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2004 ACID DEPOSITION ASSESSMENT FOR ALBERTA

A REPORT OF THE ACID DEPOSITION ASSESSMENT GROUP

Alberta Environment

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2004 Acid Deposition Assessment for Alberta

A Report of the Acid Deposition Assessment Group,

Prepared for

Alberta Environment

by

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FORWARD

Alberta Environment adopted the Acid Deposition Management Framework developed by the Clean Air Strategic Alliance for management of acid deposition effects in Alberta. The framework was described in the report: *Application of Critical, Target, and Monitoring Loads for Evaluation and Management of Acid Deposition (AENV, 1999).* The framework prescribes a 5-year assessment cycle involving:

- Assessment of potential acid input (PAI) in each 1° latitude by 1° longitude grid cell in Alberta using the REgional Lagrangian Acid Deposition (RELAD) model.
- Evaluation of RELAD model-based PAI estimates using monitoring data.
- Revision of receptor sensitivity, as appropriate, based on new data.
- Comparison of PAI to receptor sensitivity. Management actions for acidifying emissions are required if monitoring, target, or critical loads are exceeded.
- Review, and possible revision, of the framework.

The Acid Deposition Assessment Group (ADAG) was appointed by Alberta Environment to guide the assessment and review the framework. ADAG consists of representatives from government, industry, and environmental organizations. Three documents were produced:

- an acid deposition assessment report
- a framework review report, and
- an acid deposition management framework document.

This document is the acid deposition assessment report that summarizes the results of the 2004 assessment.

Lawrence Cheng
Chair, Acid Deposition Assessment Group
Environmental Policy Branch

SUMMARY

Acid deposition occurs when acid-forming pollutants emitted from anthropogenic and other processes undergo complex chemical reactions in the atmosphere and are deposited on the earth's surface. Management of acidic deposition requires an integrated approach that includes measurement and estimation of emissions and deposition, and evaluation of the effects of deposition on receiving ecosystems.

Alberta Environment formed an Acid Deposition Assessment Group to provide inputs to an evaluation of provincial acidifying emissions and resulting acid deposition levels and effects in Alberta. This evaluation is required every five years under the Acid Deposition Management Framework. This report presents the current state of knowledge of provincial acidifying emissions and interpretations of resulting acid deposition levels and effects in the province of Alberta as part of the 2004 acid deposition assessment.

Potential Acid Input in Alberta

The REgional Lagrangian Acid Deposition (RELAD) model was used to predict annual potential acid input (PAI) in Alberta for the years 1995, 2000, and 2010 (projected). The Acid Deposition Assessment Group revised the receptor sensitivity map originally developed for Alberta broken down by grid cells. New receptor sensitivity data indicated that a Provost-Esther area grid cell and an adjacent grid cell in Alberta should be changed from "high sensitivity" to "moderate sensitivity." This change is reflected in the revised receptor sensitivity map for Alberta shown in Figure S-1.

RELAD modeled PAI results were compared to the revised receptor sensitivity map by estimating the amount of annual acid deposition as percentage of critical, target, and monitoring loads for each grid cell in Alberta. Critical loads are aimed at protecting ecosystems from acid deposition. Allowable critical loads for Alberta are set at 0.25, 0.50, and 1.00 keq H^+/ha/yr for sensitive, moderately sensitive, and low sensitivity soils, respectively. Target loads are set at 0.22, 0.45, and 0.9 keq H^+/ha/yr for sensitive, moderately sensitive, and low sensitivity soils, respectively. Finally, monitoring loads are set at 0.17, 0.35, and 0.7 keq H^+/ha/yr for sensitive, moderately sensitive, and low sensitivity soils, respectively. When monitoring loads are exceeded, additional monitoring and receptor sensitivity studies are required to be undertaken.

The most important finding of this assessment is that RELAD model results for the years 1995, 2000, and 2010 indicate that current and projected acid deposition loading is below established monitoring load criteria (Figure S-2).

Evaluation of Acid Deposition Model Predictions

Field data for three stations monitoring acid deposition in Alberta indicate that PAI loadings are higher than RELAD results. A caution is noted that field data apply to very localized areas while

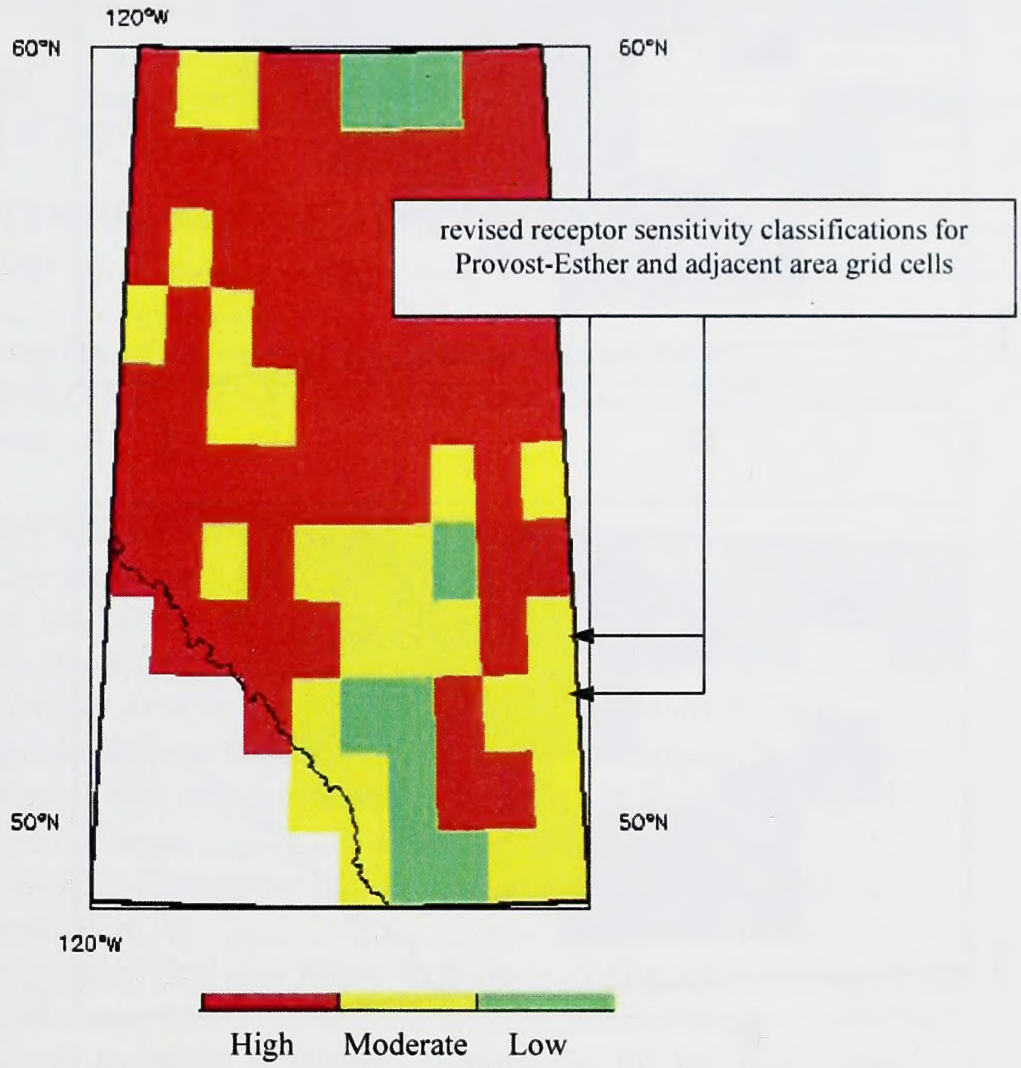

Figure S-1 Revised receptor sensitivity map based on work of the Alberta Environment Acid Deposition Assessment Group.

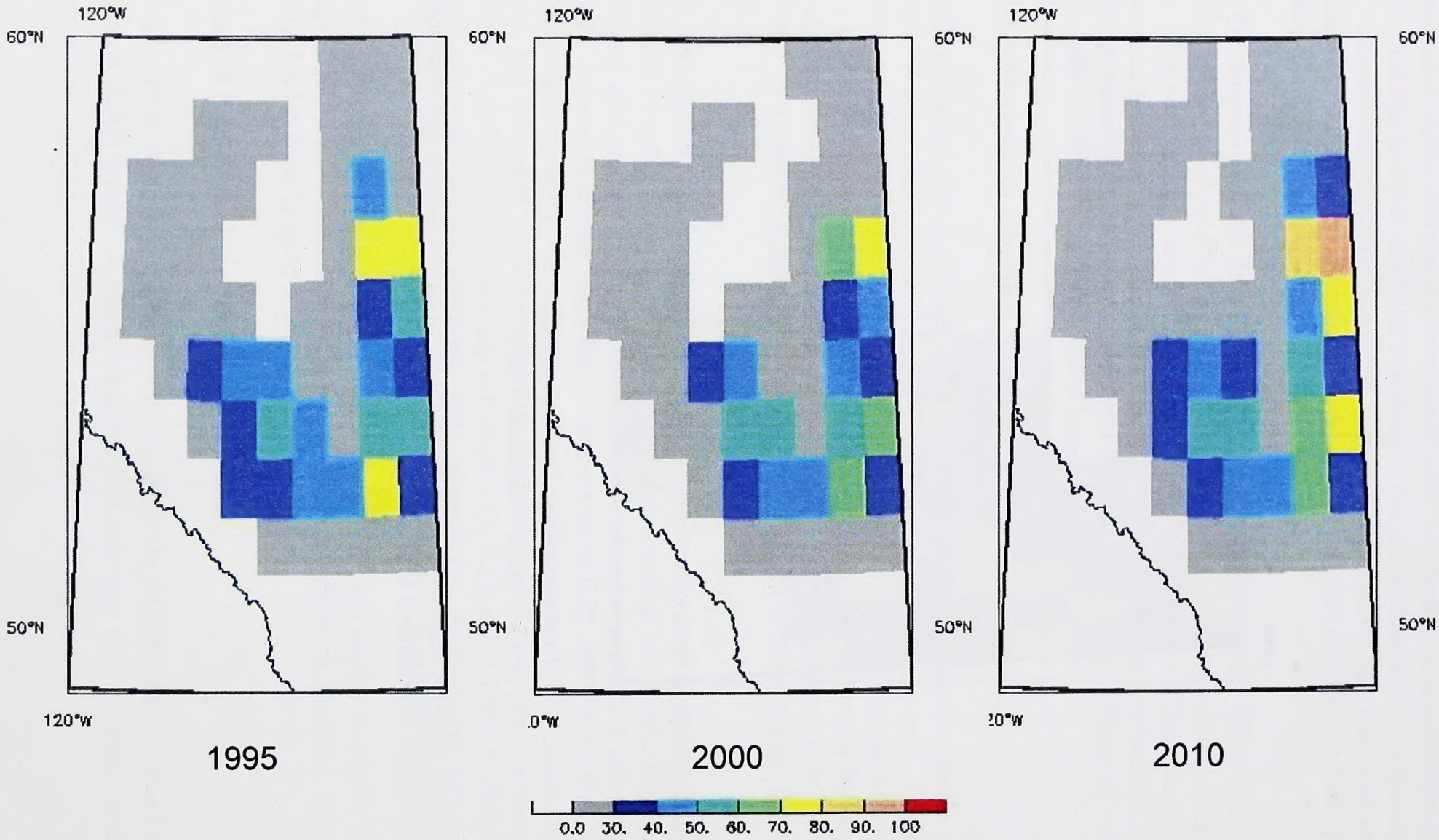

Figure S-2 Revised acid deposition loading in Alberta as a percent (%) of the monitoring load for the years 1995, 2000, and 2010 (projected) (values below zero indicate that base cation deposition exceeds acid deposition).

TABLE OF CONTENTS

SUMMARY i

LIST OF TABLES viii

LIST OF FIGURES ix

1.0 INTRODUCTION 1
1.1 Objective of Report 1

2.0 MODELED POTENTIAL ACID INPUT IN ALBERTA 3
2.1 Methodology 3
2.2 Results 4
2.2.1 Selection of Representative Meteorological Year 4
2.2.2 RELAD Runs Using 1995, 2000, and Projected 2010 Emissions Data 8

3.0 EVALUATION OF MODEL PREDICTIONS 22
3.1 Wet and Dry Deposition Measurement Data for Alberta 22
3.1.1 Wet Deposition Measurement Data 22
3.1.2 Dry Deposition Measurement Data 25
3.1.3 Potential Acid Input from Wet and Dry Deposition Data 27
3.1.4 Comparisons to Regional Acid Deposition Model Predictions 28
3.2 Field Studies of Soil and Surface Water Quality in Relation to Acid Deposition in Alberta 34
3.2.1 Sensitivity Categories of Soil and Water to Incoming Acidic Deposition 34
3.2.2 Potential of Soil and Water to Reduce Acidity of Incoming Acidic Deposition 37
3.2.3 Overall Receptor Sensitivity Assignments for Soil and Water 37
3.2.4 Reassessment of Receptor Sensitivity for Provost-Esther Grid Cell 38
3.2.5 Investigation of Acid Deposition Inputs and Soil/Forest Chemistry for Jack Pine Forests in Wood Buffalo Region 39

4.0 UPDATE OF RECEPTOR SENSITIVITY FOR ALBERTA 41

5.0 COMPARISON OF MODELED DEPOSITION TO RECEPTOR SENSITIVITY 42

6.0 SCIENCE GAPS 46
6.1 Status of Previous Identified Scientific Gaps 46
6.1.1 Aquatic Sensitivity 46
6.1.2 Mineral Soil Sensitivity 46
6.1.3 Wetland (Organic Soil) Sensitivity 46

RELAD results represent average PAI loadings over a very large area (approximately 110 km by 60 km or 6,660 km^2). In addition, RELAD model results represent average conditions based on long-term time-averaged meteorological conditions while deposition estimates derived from field monitoring data represent meteorological and emission conditions for a distinct, shorter time period. As the RELAD model and the monitoring programs are not run under exactly the same conditions, they are not directly comparable.

RELAD model results were also compared to selected time-averaged field monitoring data (i.e., annual SO_2 concentrations, total annual sulphur wet deposition, and total annual nitrogen wet deposition) from selected stations in Alberta. Coefficient of determination (R^2) values were calculated to offer insights about how well monitoring data explained variability in RELAD model results:

- Favourable results were observed for year 1995 (and 2000) annual SO_2 concentrations as 71% (and 78%) of the variability in RELAD modeled SO_2 concentrations could be explained by monitored SO_2 concentrations, respectively. The remaining 29% (and 22%) of variability is due to unexplained factors, respectively.
- Less than favourable results were observed for year 1995 (and 2000) total annual sulphur wet deposition as only 50% (and 49%) of the variability in RELAD modeled total annual sulphur wet deposition could be explained by monitored total annual sulphur wet deposition, respectively. The remaining 50% (and 49%) of variability is due to unexplained factors, respectively.
- Favourable results were observed for year 1995 (and 2000) total annual nitrogen wet deposition as 70% of the variability in RELAD modeled total annual nitrogen wet deposition could be explained by monitored total annual nitrogen wet deposition for both years. The remaining 30% of variability is due to unexplained factors.

Current Science Issues and Gaps/Future Work

Status of the scientific gaps identified in the 1999 assessment is reviewed. These gaps are on:

- Aquatic Sensitivity
- Mineral Soil Sensitivity
- Wetland (Organic Soil) Sensitivity
- Role of Nitrogen Fertilization
- Ecological Monitoring
- Survey Sampling of Receptor Sensitivity.

New scientific Gaps are also identified and consideration for future works are provided on:

- Acid Deposition Field Measurements
- Aquatic Sensitivity
- Criteria for Assessing Acidification in Soils
- BC/Al Ratio Dose-response Relationships in Soils for Boreal Forest Species
- Role of Nitrogen in Soil Acidification.

6.1.4 Role of Nitrogen Fertilization 47
6.1.5 Ecological Monitoring 47
6.1.6 Survey Sampling of Receptor Sensitivity 47
6.2 New Scientific gaps and Suggested Future Work 47
6.2.1 Acid Deposition Field Measurements 47
6.2.2 Aquatic Sensitivity 47
6.2.3 Criteria for Assessing Acidification in Soils 48
6.2.4 BC/Al Ratio Dose-response Relationships in Soils for Boreal Forest Species 48
6.2.5 Role of Nitrogen in Soil Acidification 48
6.2.6 Nitrogen Cycling 49
6.2.7 Need for Updating of the Alberta Soil Sensitivity Ratings 49

7.0 REFERENCES **50**

Appendix I Alberta Environment Acid Deposition Assessment Group (ADAG) Membership **57**

Appendix II RELAD Runs for Selection of Representative Meteorological Year between 1971 and 2000 ..... **58**

Appendix III Statistical Measures used to Examine RELAD Results for Chemical Species' Concentrations and Deposition Rates **68**

Appendix IV Supporting Documentation for Field Studies of Soil and Surface Water Quality in Relation to Acid Deposition in Alberta **80**

LIST OF TABLES

Table 1 Alberta's total annual emissions of SO_2 and NO_x for 1995, 2000, and 2010 used for RELAD modeling. 8

Table 2 Net annual Potential Acid Input from wet deposition (PAI_{wet}) in keq H^+/ha/yr at monitoring stations in Alberta. 24

Table 3 Annual Potential Acid Input from dry deposition (PAI_{dry}) in keq H^+/ha/yr at monitoring stations in Alberta 27

Table 4 Estimate of Total Potential Acid Input ($PAI_{wet} + PAI_{dry}$) at selected air monitoring stations in Alberta (keq H^+/ha/yr). 28

LIST OF FIGURES

Figure 1 Alberta's Acid Deposition Management Framework 2

Figure 2 RELAD 30-year mean SO_2 concentration ($\mu g\ m^{-3}$). 5

Figure 3 RELAD 30-year mean SO_2 dry deposition (keq H^+/ha/yr). 6

Figure 4 RELAD 30-year mean SO_2 wet deposition (keq H^+/ha/yr). 7

Figure 5 Annual SO_2 emissions (kt/yr) for the RELAD model domain in 1995, 2000, and 2010 (projected). 9

Figure 6 Annual NO_x emissions (kt/yr as NO_2) for the RELAD model domain in 1995, 2000, and 2010 (projected). 10

Figure 7 RELAD results for annual average SO_2 concentrations for the years 1995, 2000, and 2010 (projected) ($\mu g\ m^{-3}$). 13

Figure 8 RELAD results for annual dry deposition of total S for the years 1995, 2000, and 2010 (projected) (kg/ha/yr). 14

Figure 9 RELAD results for annual wet deposition of total S for the years 1995, 2000, and 2010 (projected) (kg/ha/yr). 15

Figure 10 RELAD results for annual average NO_x concentrations as NO_2 for the years 1995, 2000, and 2010 (projected) ($\mu g\ m^{-3}$). 16

Figure 11 RELAD results for annual dry deposition of total N for the years 1995, 2000, and 2010 (projected) (kg/ha/yr). 17

Figure 12 RELAD results for annual wet deposition of total N for the years 1995, 2000, and 2010 (projected) (kg/ha/yr). 18

Figure 13 RELAD results for annual deposition of total S and N for the years 1995, 2000, and 2010 (projected) (kg/ha/yr). 19

Figure 14 Composite base cation deposition (keq/ha/yr) interpolated from existing monitoring data, where ⋇ denotes locations of precipitation quality monitoring stations. 20

Figure 15 RELAD results for annual PAI for the years 1995, 2000, and 2010 (projected) (keq H^+/ha/yr). 21

Figure 16 Wet deposition monitoring stations operated in Alberta 23

Figure 17 Dry deposition monitoring stations operated in Alberta 26

Figure 18 Grid cells containing selected acid deposition monitoring stations in Alberta along with RELAD results for annual PAI (keq H^+/ha/yr) for the year 2000. 29

Figure 19 Comparison of monitored versus RELAD modeled annual SO_2 concentrations at selected monitoring sites in Alberta and Saskatchewan using 1995 and 2000 emissions data. 30

Figure 20 Parkland Airshed Management Zone passive air monitoring network annual average ambient SO_2 levels and total sour gas plant emissions of SO_2 (2000 to 2005) 31

Figure 21 Comparison of monitored versus RELAD modeled annual wet sulphur deposition at selected monitoring sites in Alberta using 1995 and 2000 emissions data. 32

Figure 22 Comparison of monitored versus RELAD modeled annual wet nitrogen deposition at selected monitoring sites in Alberta using 1995 and 2000 emissions data. 33

Figure 23 Revised receptor sensitivity map based on work of the Alberta Environment ADAG. 41

Figure 24 Revised acid deposition loading as a percent (%) of the critical load for the years 1995, 2000, and 2010 (projected) (values below zero indicate that base cation deposition exceeds acid deposition) 43

Figure 25 Revised acid deposition loading as a percent (%) of the target load for the years 1995, 2000, and 2010 (projected) (values below zero indicate that base cation deposition exceeds acid deposition) 44

Figure 26 Revised acid deposition loading as a percent (%) of the monitoring load for the years 1995, 2000, and 2010 (projected) (values below zero indicate that base cation deposition exceeds acid deposition). 45

1.0 INTRODUCTION

Acid deposition occurs when acid-forming pollutants emitted from anthropogenic and other processes undergo complex chemical reactions in the atmosphere and are deposited on the earth's surface. Acidic pollutants can fall to the earth as wet deposition (i.e., in rain, snow, cloud, and fog) or dry deposition (i.e., as dry particles or as a gas).

The main chemical precursors leading to acidic pollutants are sulphur dioxide (SO_2) and oxides of nitrogen (NO_x). Reactions of these pollutants with water, oxygen, carbon dioxide, and sunlight in the atmosphere produce acidic pollutants, e.g. sulphuric acid (H_2SO_4), nitric acid (HNO_3), and nitrous acid (HNO_2). These and other acidic pollutants can be transported long distances in the atmosphere from their sources and eventually be deposited in ecosystems over broad regional scales and in locations far from the emission sources. Under certain conditions, such as limited buffering capacity of ecosystems, acid deposition can adversely affect lakes, rivers, soils, and forests.

Management of acidic deposition requires an integrated approach that includes measurement and estimation of emissions and deposition, and evaluation of the effects of deposition on recipient ecosystems. In Alberta, a management framework has been developed and is based on four levels of acid deposition: pre-industrial deposition (background), current level of deposition, target load, and critical load. Each level of deposition corresponds with a need to undertake specific management practices – continuous improvement, emissions management, and emissions reduction. This approach is a key component of the Alberta Acid Deposition Management Framework (Figure 1).

1.1 Objective of Report

Alberta Environment (AENV) formed an Acid Deposition Assessment Group (ADAG) to provide input to an evaluation of provincial acidifying emissions and resulting acid deposition levels and effects in Alberta (Appendix I). This evaluation is required every five years under the Acid Deposition Management Framework (AENV, 1999). The objective of this report is to compile the current state of knowledge of provincial acidifying emissions and resulting acid deposition levels and effects in the province of Alberta as part of the 2004 acid deposition assessment.

The following information is presented in this report:

- Estimates of modeled potential acid input (PAI) in Alberta (Section 2).
- An evaluation of acid deposition model predictions along with a discussion of field studies conducted in Alberta during the past five years examining soil and surface water quality in relation to exposure to acid deposition (Section 3).
- An update of the receptor sensitivity database for Alberta (Section 4).
- A comparison of modeled PAI to receptor sensitivity (Section 5).

- Current science gaps and recommendations (Section 6).

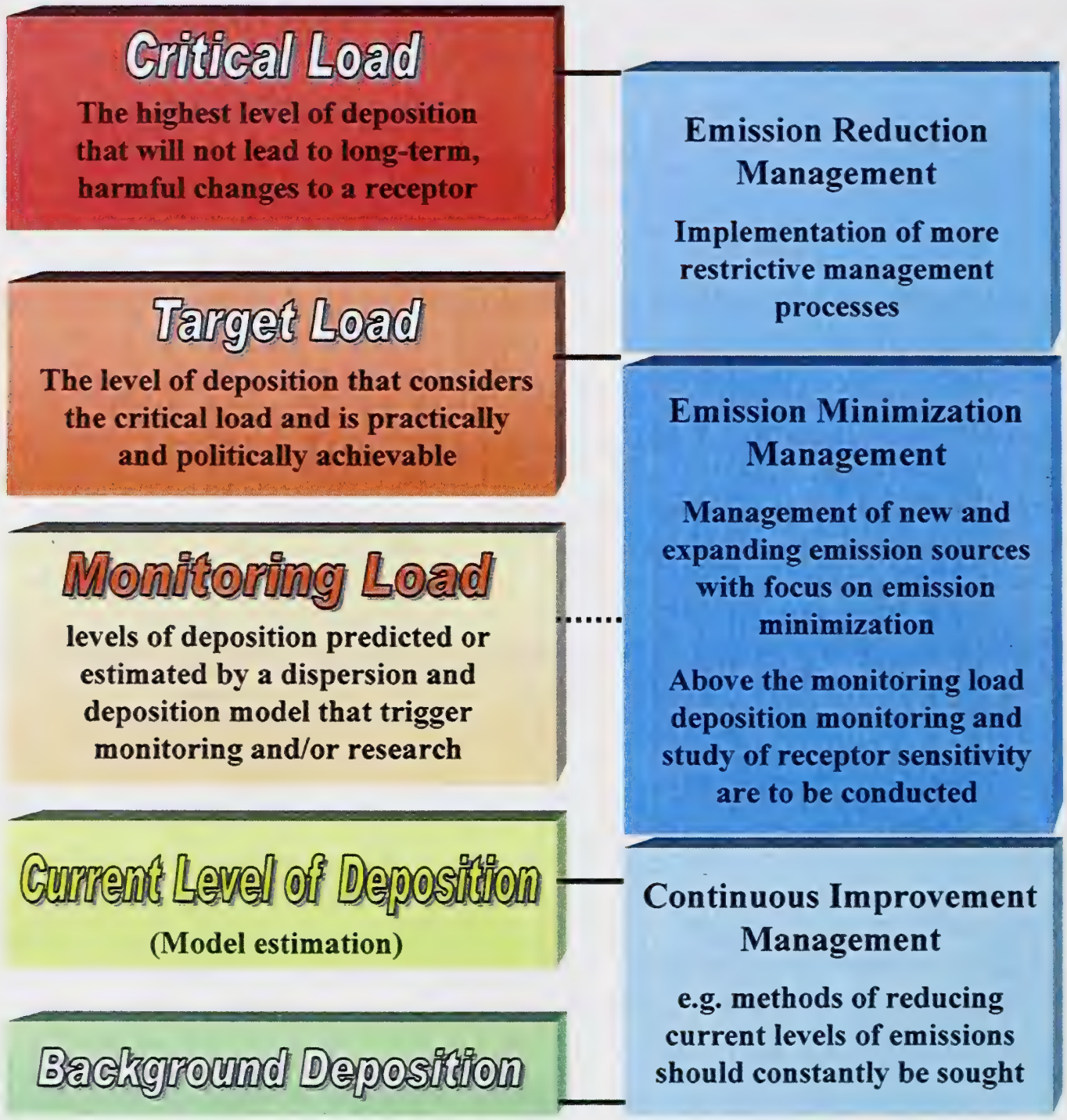
Critical Load
The highest level of deposition that will not lead to long-term, harmful changes to a receptor
Target Load
The level of deposition that considers the critical load and is practically and politically achievable
Monitoring Load
levels of deposition predicted or estimated by a dispersion and deposition model that trigger monitoring and/or research
Current Level of Deposition
(Model estimation)
Background Deposition
Emission Reduction Management
Implementation of more restrictive management processes
Emission Minimization Management
Management of new and expanding emission sources with focus on emission minimization
Above the monitoring load deposition monitoring and study of receptor sensitivity are to be conducted
Continuous Improvement Management
e.g. methods of reducing current levels of emissions should constantly be sought

Figure 1 Alberta's Acid Deposition Management Framework.

2.0 MODELED POTENTIAL ACID INPUT IN ALBERTA

An important tool for understanding and managing acid deposition is the ability to quantitatively relate amounts and geographic distributions of acidifying emissions to resulting air-concentration patterns and wet-, dry-, and total-deposition patterns of acid forming pollutants (Environment Canada (ENVC), 2005). Regional acid deposition models provide a suitable means of providing this information.

Regional acid deposition models take information on emission rates of acidifying pollutants to the atmosphere and meteorological conditions to predict atmospheric concentrations and deposition of these pollutants and their products (ENVC, 2005). One such model is the REgional Lagrangian Acid Deposition (RELAD) model. RELAD is a three-layer mass-conserving regional scale Lagrangian model that simulates ground-level ambient concentrations and wet and dry deposition of SO_2, H_2SO_4, ammonium sulphate ($(NH_4)_2SO_4$), NO_x (nitrogen dioxide (NO_2) + nitric oxide (NO)), HNO_3, and ammonium nitrate (NH_4NO_3) (AENV, 1999; Cheng *et al.*, 1995). It is based upon a US Environmental Protection Agency Lagrangian sulphur deposition model named RELMAP (REgional Lagrangian Model of Air Pollution). Topography is not considered in the model.

2.1 Methodology

RELAD modeling was performed by Alberta Environment as part of the 2004 acid deposition assessment. A detailed description of the RELAD model is provided in Cheng *et al.* (1995). The boundaries selected for RELAD modeling were from 47°N to 65°N latitude and from 90°W to 130°W longitude, respectively (British Columbia, Alberta, Saskatchewan (SK) and portions of Manitoba, the northern Canadian territories and the north-western U.S. states), with a resolution of 1° latitude by 1° longitude. These 1° x 1° grid cells measure approximately 111 km by 60 km (AENV, 1999).

Initial RELAD modeling was performed to identify a representative meteorological year between 1971 and 2000 to use for RELAD model runs comparing acid deposition for current and future years in Alberta. Once a representative meteorological year was selected, RELAD was run again using 1995, 2000, and projected 2010 emissions data in order to show potential changes to geographic distributions of acidifying emissions in Alberta during these periods.

The following tasks were completed as part of the RELAD modeling exercise:

1. RELAD was run using each of 30 years of meteorological data (1971 to 2000) and emission inventory data for year 1995.
2. Thirty-year means for chemical species' concentrations and deposition rates were predicted.
3. Statistical measures were calculated for the 30-year means of chemical species' concentrations and deposition rates and for each individual year.

4. Based on a comparison of scores assigned to these statistical measures for individual years versus the 30-year means, a representative meteorological year was chosen for subsequent RELAD model runs to represent updated acidifying emissions loading in Alberta.
5. Once a representative year was identified, RELAD was run again using 1995, 2000, and projected 2010 emission inventory data to determine the deposition in each 1° by1° grid cell.
6. RELAD model results were compared to selected time-averaged field monitoring data (i.e. annual SO_2 concentrations, total annual sulphur wet deposition, and total annual nitrogen wet deposition) from selected stations in Alberta.
7. Predicted deposition levels for each 1° by1° grid cell were then compared to the monitoring, target, and critical loads for that cell.

2.2 Results

2.2.1 Selection of Representative Meteorological Year

Typical examples of initial RELAD model results are presented in Figures 2 through 4 representing 30-year mean SO_2 concentrations and 30-year dry and wet deposition rates, respectively. Initial RELAD model results for other species are presented in Appendix II.

Statistical measures calculated from initial RELAD model runs for individual year (1971 to 2000) and 30-year means of chemical species' concentrations and deposition rates are tabulated in Appendix III. Results of the comparison of scores assigned to these statistical measures for individual year versus 30-year means are also presented in Appendix III.

The tabulated results in Appendix III initially pointed to the year 1980 as a suitable meteorological year to use for subsequent RELAD runs of 1995, 2000, and projected 2010 emissions data. As a final check, RELAD results for the thirty-year mean (1971 to 2000) were visually compared to results for selected individual meteorological years (1980, 1990, and 1995) in plots for the following model outputs (Appendix III):

- total sulphur concentration
- total nitrogen concentration
- total sulphur deposition
- total nitrogen deposition
- total nitrogen and sulphur deposition

Although not exact, these plots visually showed that RELAD results for the 1980 meteorological year were closer to the thirty-year mean (1971 to 2000) results compared to 1990 and 1995 meteorological year results. This was observed by a smaller amount of difference in "thirty-year mean (1971 to 2000) results" minus "individual year (1980, 1990, and 1995) results. These

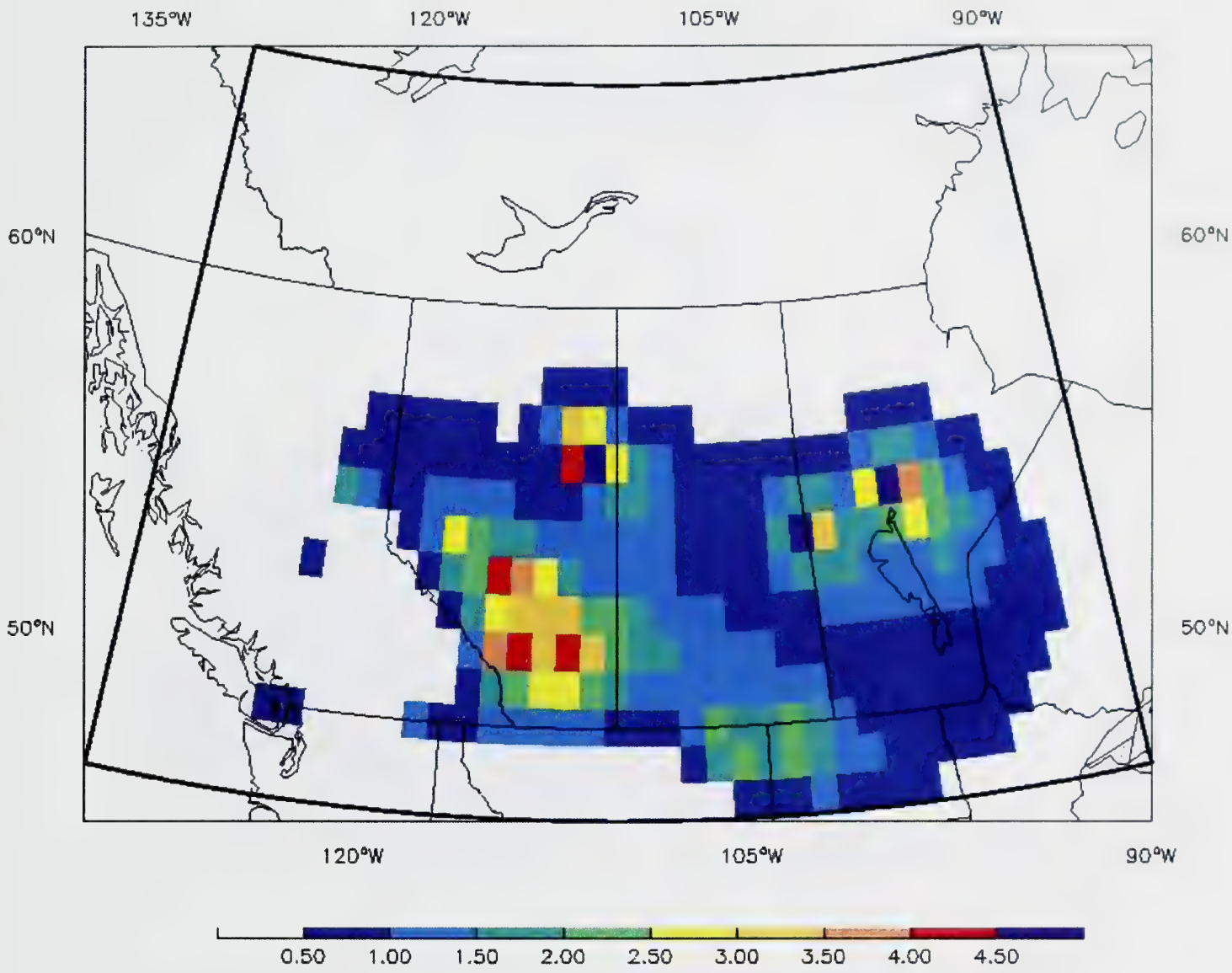

Figure 2 RELAD 30-year mean SO_2 concentration ($\mu g\ m^{-3}$).

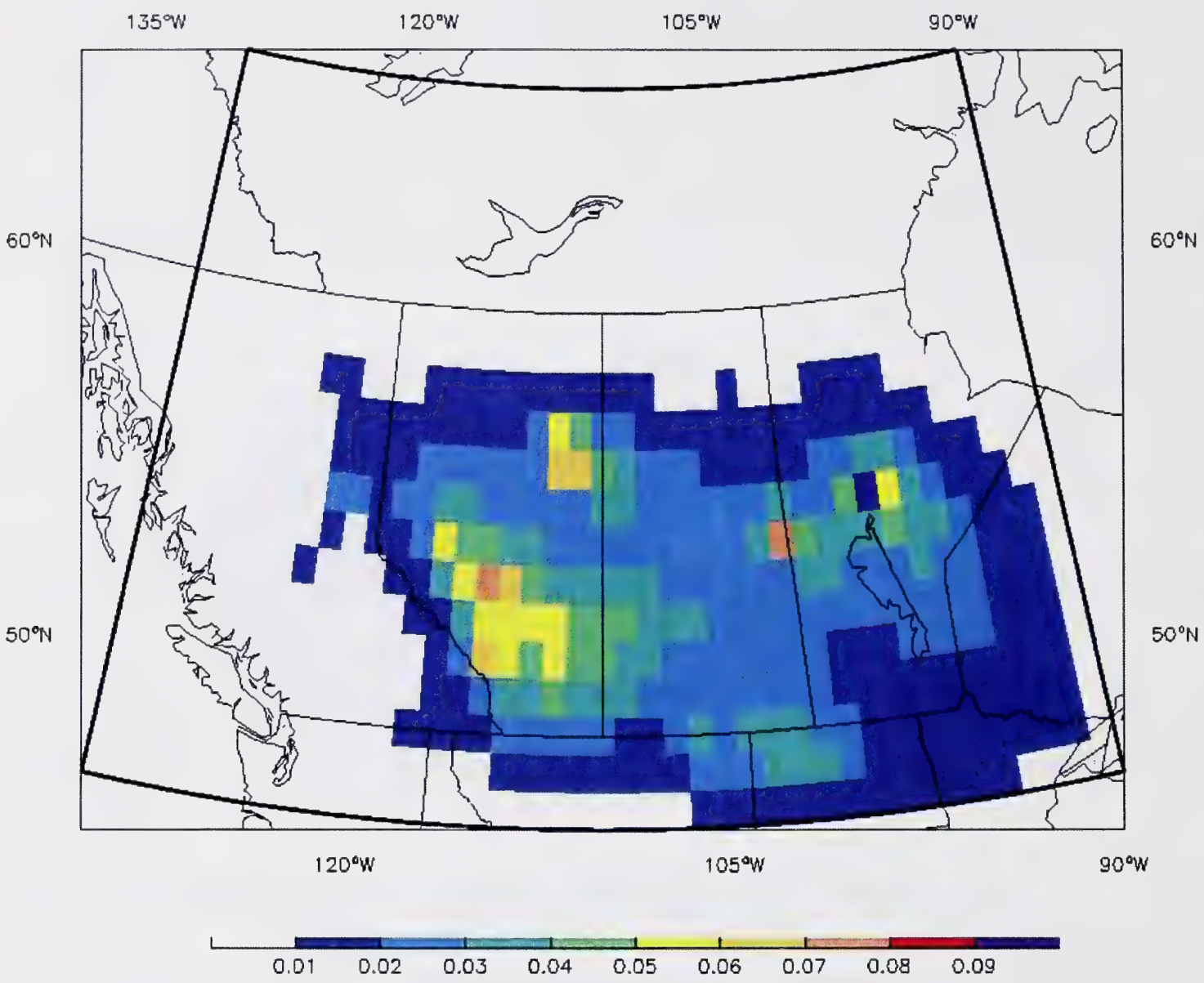

Figure 3 RELAD 30-year mean SO_2 dry deposition (keq H^+/ha/yr).

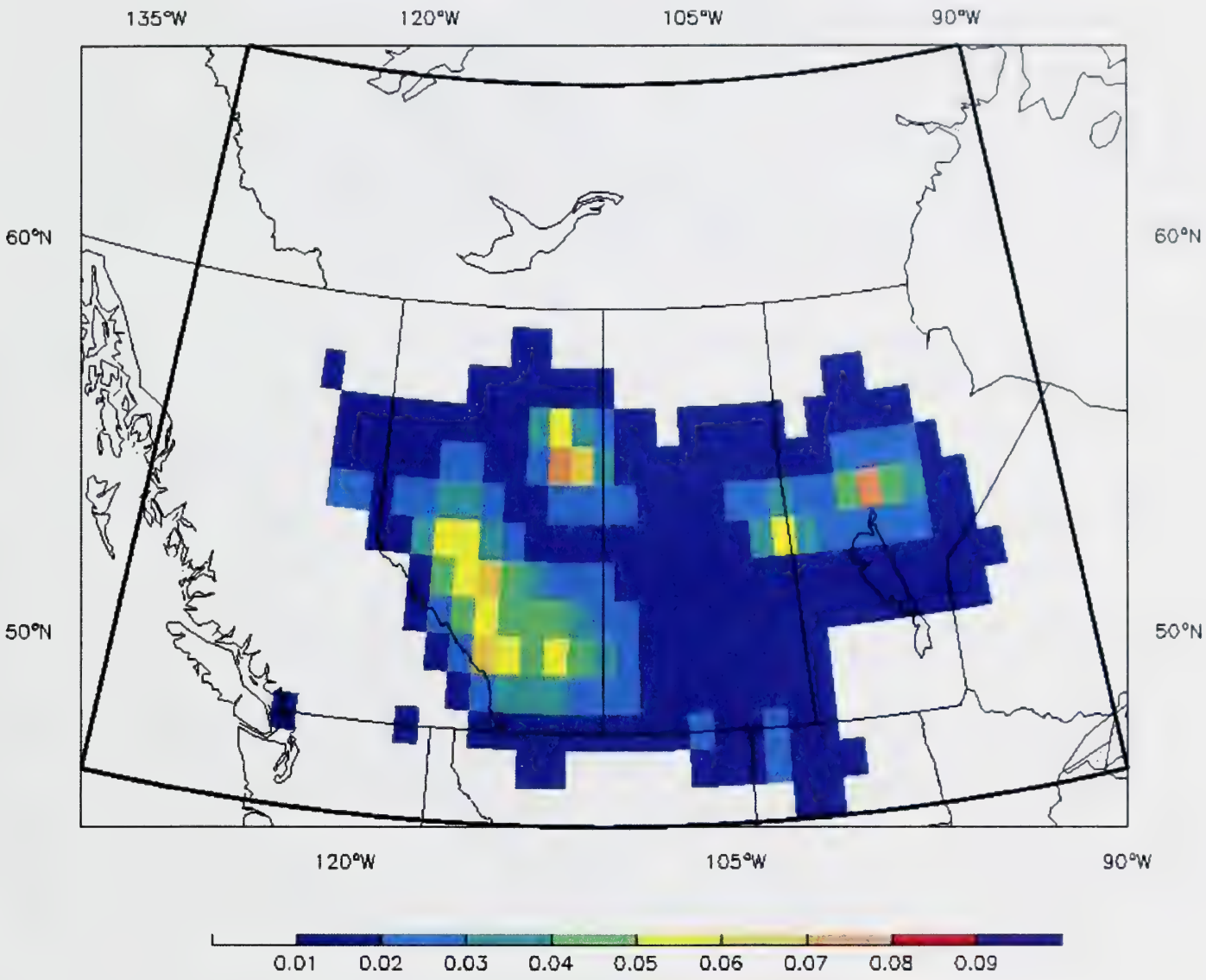

Figure 4 RELAD 30-year mean SO_2 wet deposition (keq H^+/ha/yr).

differences can be observed in Figures III.2, III.4, III.6, and III.8 in Appendix III). From this it was concluded that the 1980 meteorological year was suitable to represent long-term average meteorological conditions for use in subsequent RELAD runs of 1995, 2000, and projected 2010 sulphur and nitrogen emissions in Alberta.

2.2.2 RELAD Runs Using 1995, 2000, and Projected 2010 Emissions Data

Using 1980 as the representative meteorological year, RELAD was run using 1995, 2000, and projected 2010 emissions data for SO_2 and NO_x provided by the Pollution Data Branch of Environment Canada. Total annual emissions of SO_2 and NO_x used for these years are shown in Table 1. Figures 5 and 6 show annual SO_2 and NO_x emissions, respectively for the RELAD model area in the years 1995, 2000, and 2010.

Table 1 Alberta's total annual emissions of SO_2 and NO_x for 1995, 2000, and 2010 used for RELAD modeling.

	SO_2 (kt/yr)	NO_x (kt/yr)
1995	608	667
2000	502	718
2010 projected	563	837

Data on emissions of pollutants responsible for acid deposition in Canada are compiled in the Criteria Air Contaminants (CAC) emissions inventory. The inventory is managed by Environment Canada (Ottawa, ON) with data from environmental agencies representing the provinces, territories, and specific regions of Canada. Emission sources in the inventory include: industrial facilities; non-industrial fuel combustion (which includes residential and electric power generation); transportation vehicles; incineration activities; and various other sources such as surface coating, road dust, and forest fires.

Historically, the CAC inventory has been updated every five years. Currently, the inventory has emission estimates and forecasts from 1970 to 2020 for NO_x, SO_2, particulate matter ($PM_{2.5}$ and PM_{10}), and ammonia. Starting in 2002, a number of industrial and commercial facilities with emissions above defined threshold values have also been required to report their Criteria Air Contaminants emissions to Environment Canada on an annual basis. With collection of this new information, Environment Canada plans to compile a more comprehensive emission inventories for these pollutants annually.

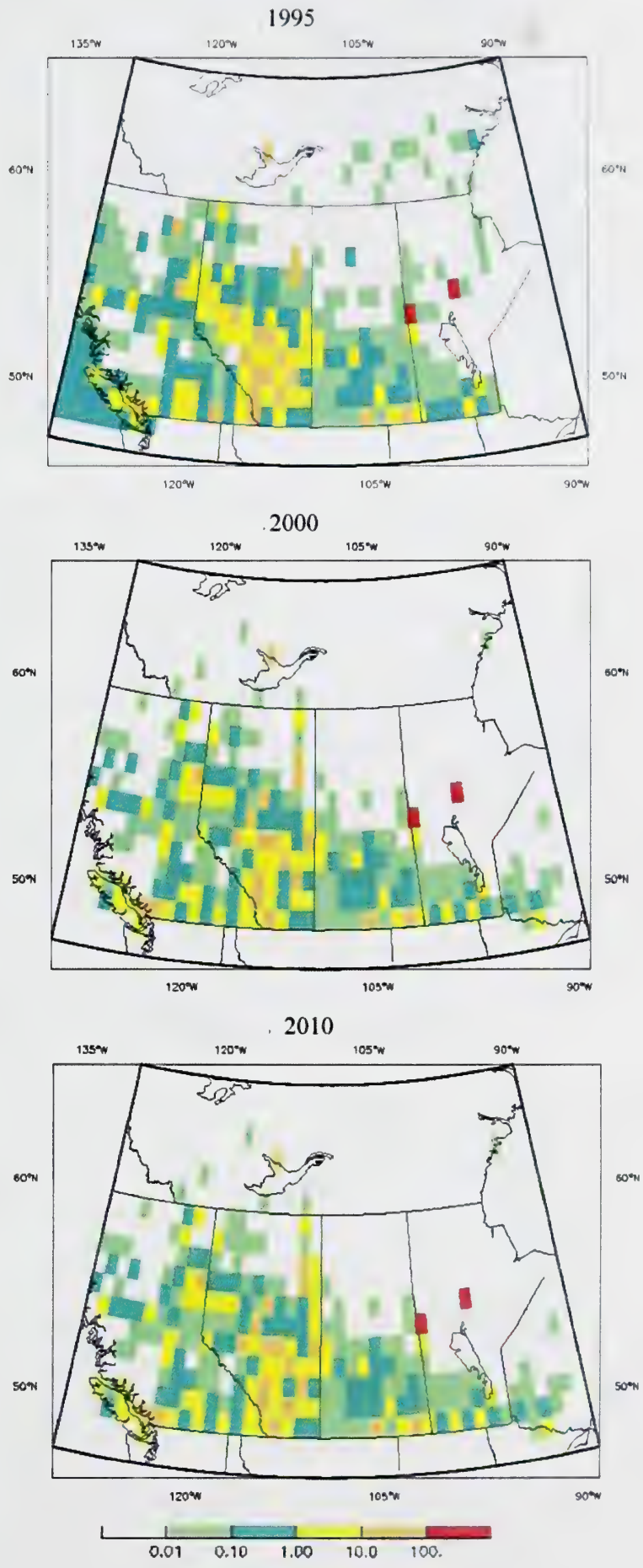

Figure 5 Annual SO_2 emissions (kt/yr) for the RELAD model domain in 1995, 2000, and 2010 (projected).

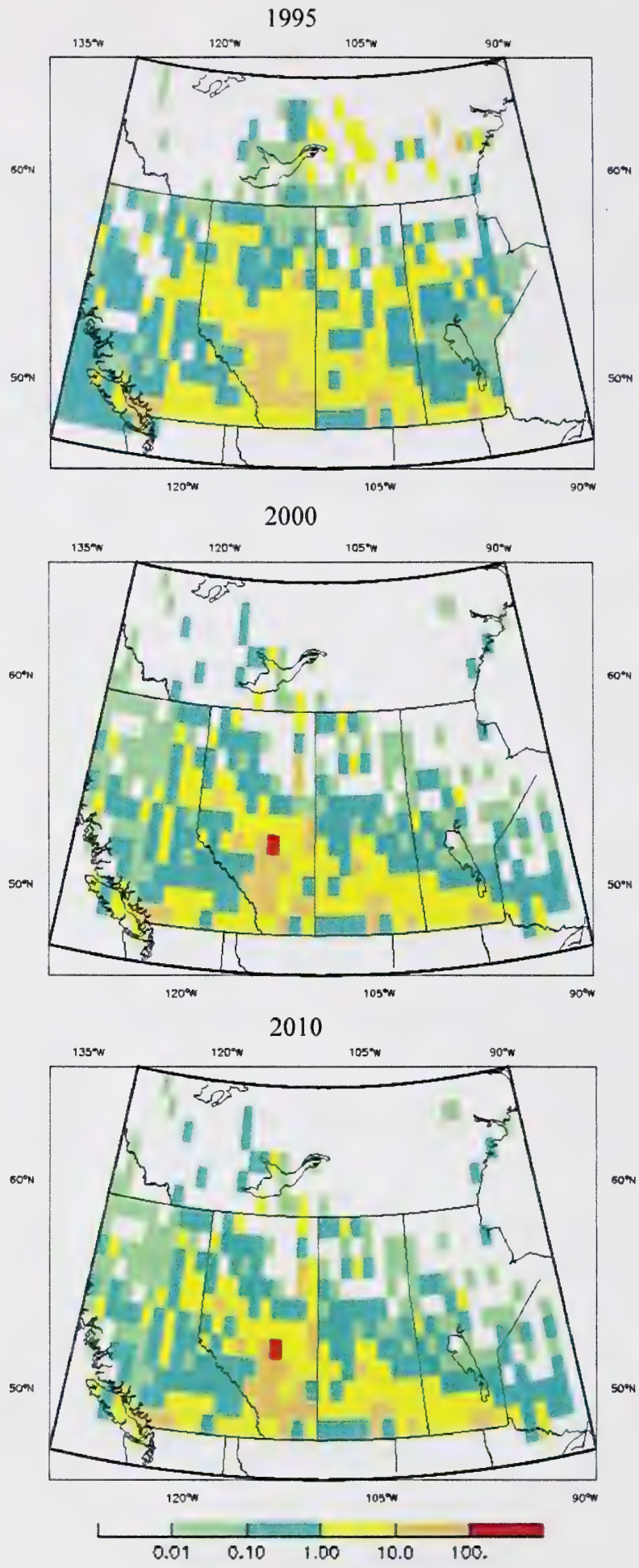

Figure 6 Annual NO_x emissions (kt/yr as NO_2) for the RELAD model domain in 1995, 2000, and 2010 (projected).

The Canadian CAC Emissions Inventory is compiled using a number of estimation techniques including: data from continuous emissions monitors (CEMs); data from source testing; mass balance data, emission factor data; and models for point sources, non-point sources, and on-road and non-road mobile sources. Emission estimation models are generally used to quantify diffuse sources of emissions such as mobile sources and road dust. The models used to estimate emissions of key pollutants are constantly being updated. The Mobile 6 model was used to estimate emissions from on-road vehicles in the 1990, 1995, and 2000 emissions inventories.

Emission data for year 2010 used in this assessment were compiled with 2010 Alberta emissions forecast data and 2000 emissions data for other provinces. The year 2010 Alberta emissions forecast data were developed by Cheminfo Services Inc. for the Clean Air Strategic Alliance (CASA) PM and Ozone Project Team (CASA), 2002). Overall CAC emissions in Alberta were projected to increase under business-as-usual conditions by Cheminfo Services Inc.

Business-as-usual conditions included continued economic growth as reflected by changes in total Gross Domestic Product projected to increase 24% between 2000 and 2010, and 56% between 2000 and 2020. The total increase in energy consumption by the Alberta economy was projected to increase at a slower pace, largely as a result of improvement in energy efficiency. Total energy consumption in Alberta was projected to increase by 20% between 2000 and 2020, although this was revised upward to reflect increased oil sands development and electric power generation.

As a result, total CAC emissions forecast by Cheminfo Services Inc. – the sum of PM, SO_2, NO_x, CO, VOCs, and NH_3 – were projected to increase 18% by 2010 over 1995 levels (Cheminfo, 2005). These slower growth rates came from anticipated energy efficiency improvements as a result of a general shift to less CAC-intensive fuels and a constant level of future emissions assumed for natural and some agricultural sources. In addition, reduced emissions from transportation were anticipated in context of improved vehicle emission standards and regulated reductions in the sulphur content of gasoline and diesel fuel.

The magnitude of projected change for each CAC was quite different. Estimates of 2010 emissions from each source category and for each CAC were developed for each of Alberta's 19 census divisions (or regions). Cheminfo Services Inc. further processed emissions forecast to sources in different industrial sectors for Environment Canada for modeling work (ENVC, 2005).

The emissions forecast for the oil sands sector was based upon information on a planned development case in environmental impacts assessment report of the Canadian Natural Resources Ltd.'s Horizon Oil Sands Project. Thus, the forecast may not include all planned developments and emissions reduction activities that were disclosed or implemented at a later time, such as the Syncrude Canada Limited Emission Reduction Project or the Approval requirements that all new and replacement mining vehicles and engines must meet latest US Environmental Protection Agency emission standards for off-road heavy-duty diesel vehicles as amended from time to time.

RELAD model results for annual average SO_2 concentrations, annual dry deposition of total S, and annual wet deposition of total S for the years 1995, 2000, and 2010 are presented in Figures 7 through 9, respectively. Model results for annual average NO_x concentrations, annual dry deposition of total N, and annual wet deposition of total N for the years 1995, 2000, and 2010 are presented in Figures 10 through 12, respectively.

RELAD model results for annual deposition of total (wet and dry) S and N for the years 1995, 2000, and 2010 are presented in Figure 13. The RELAD model estimates PAI without consideration of mitigating base cation deposition; however, co-deposition of base cations (Na^+, K^+, Mg^{2+}, and Ca^{2+}) result in a reduction of the amount of deposited acidity. As most base cation emissions are from natural sources, a different model would be required and an emissions inventory would need to be developed. Potential acid input estimated by RELAD is corrected for base cation deposition in the following ways:

- Wet deposition of base cations was estimated from readily available from precipitation quality monitoring data.
- Dry deposition of base cations was estimated from precipitation quality monitoring data using scavenging ratios to infer surface-level concentrations and deposition velocities (Chaikowsky, 2001).

Figure 14 gives base cation deposition derived from all available data in western Canada from the Canadian National Atmospheric Chemistry (NAtChem) Database. Finally, PAI was estimated by subtracting base cation deposition from total (wet and dry) S and N deposition. RELAD results for annual PAI for the years 1995, 2000, and 2010 are presented in Figure 15.

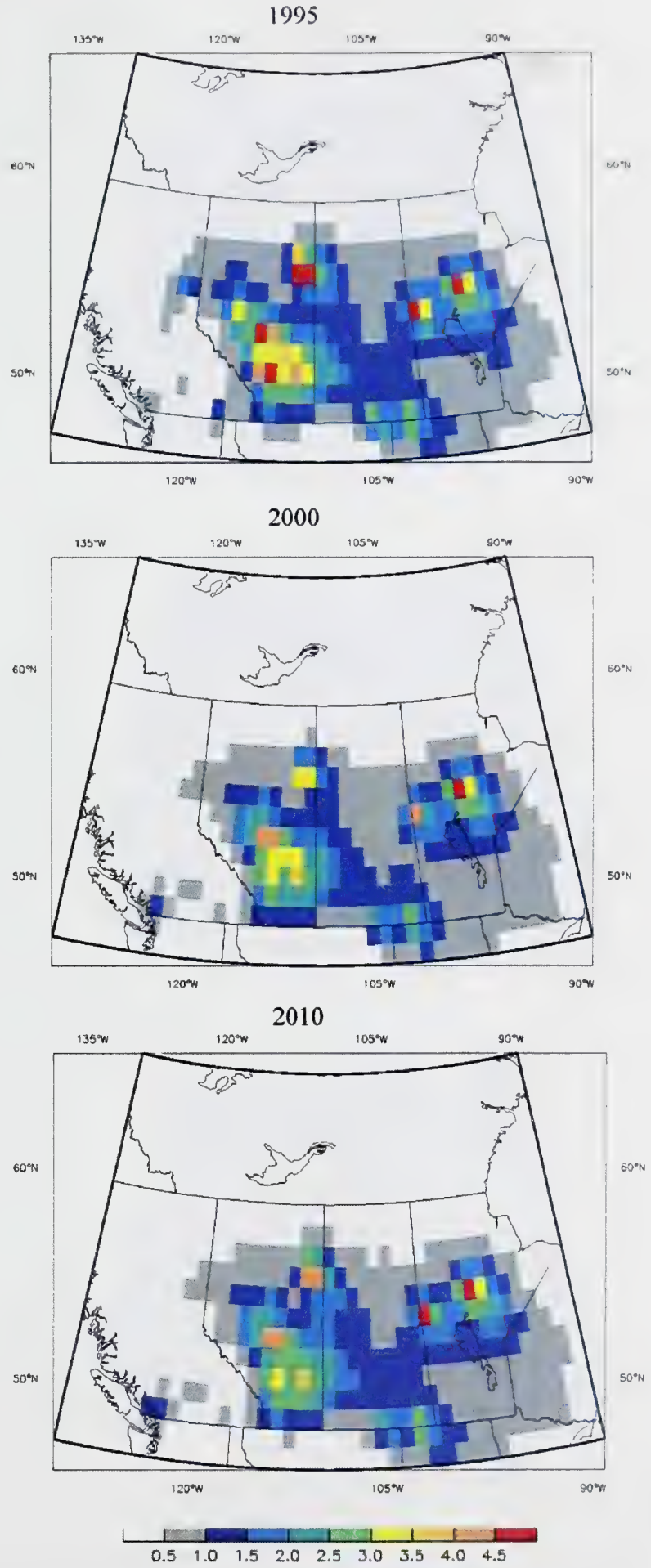

Figure 7 **RELAD results for annual average SO_2 concentrations for the years 1995, 2000, and 2010 (projected) ($\mu g\ m^{-3}$).**

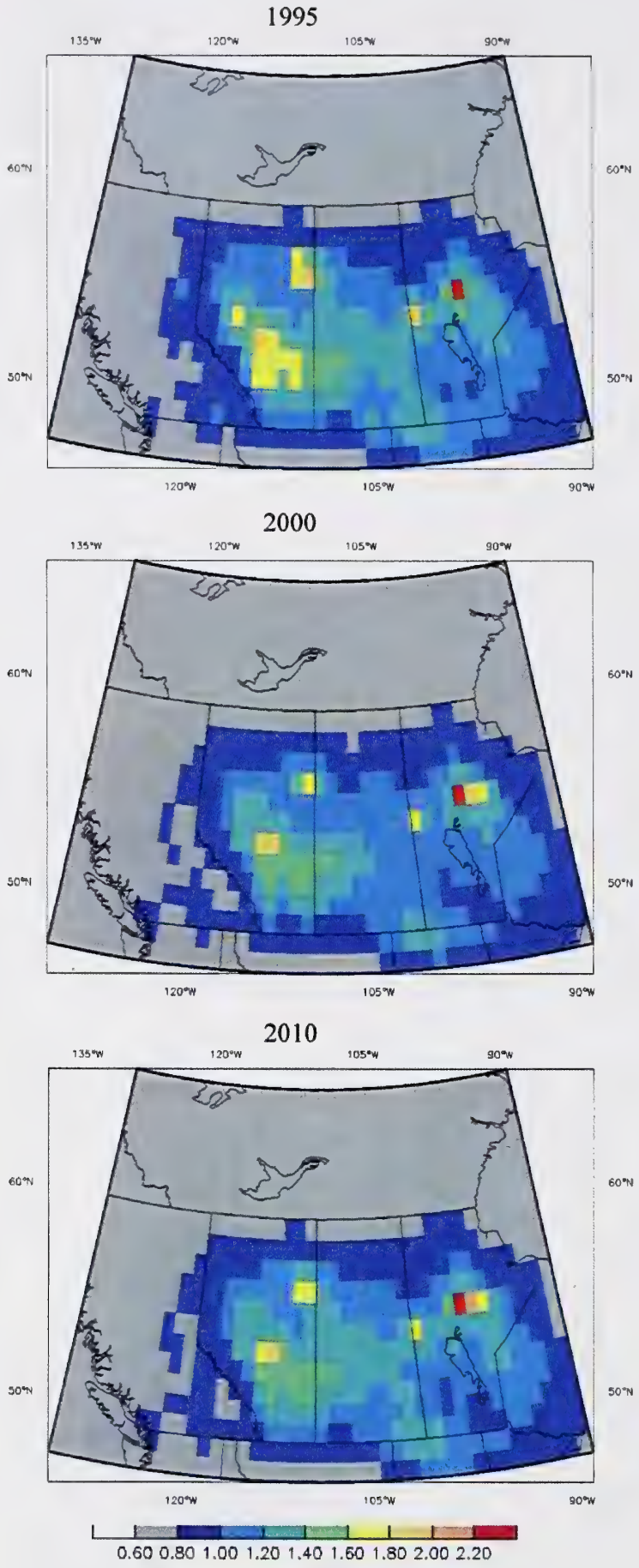

Figure 8 **RELAD results for annual dry deposition of total S for the years 1995, 2000, and 2010 (projected) (kg/ha/yr).**

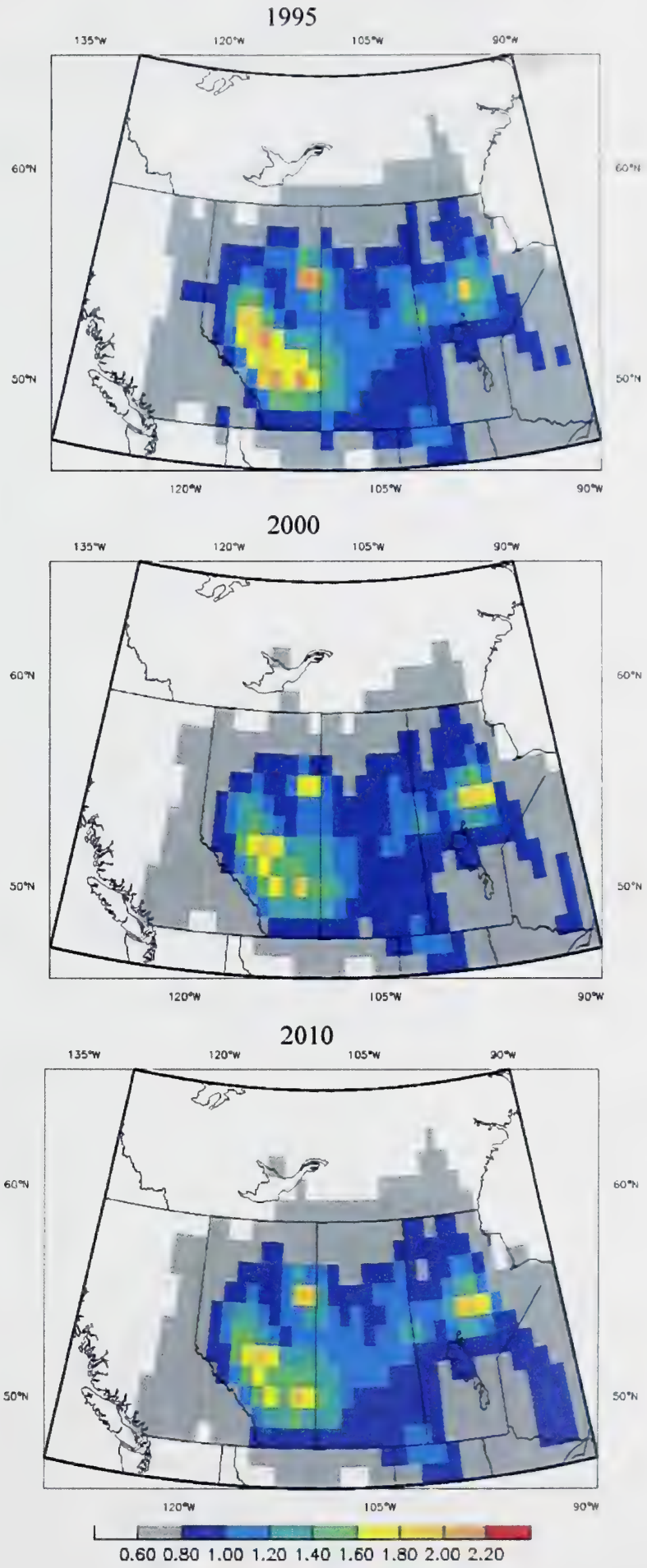

Figure 9 **RELA** **the years 1995, 2000, and 2(**

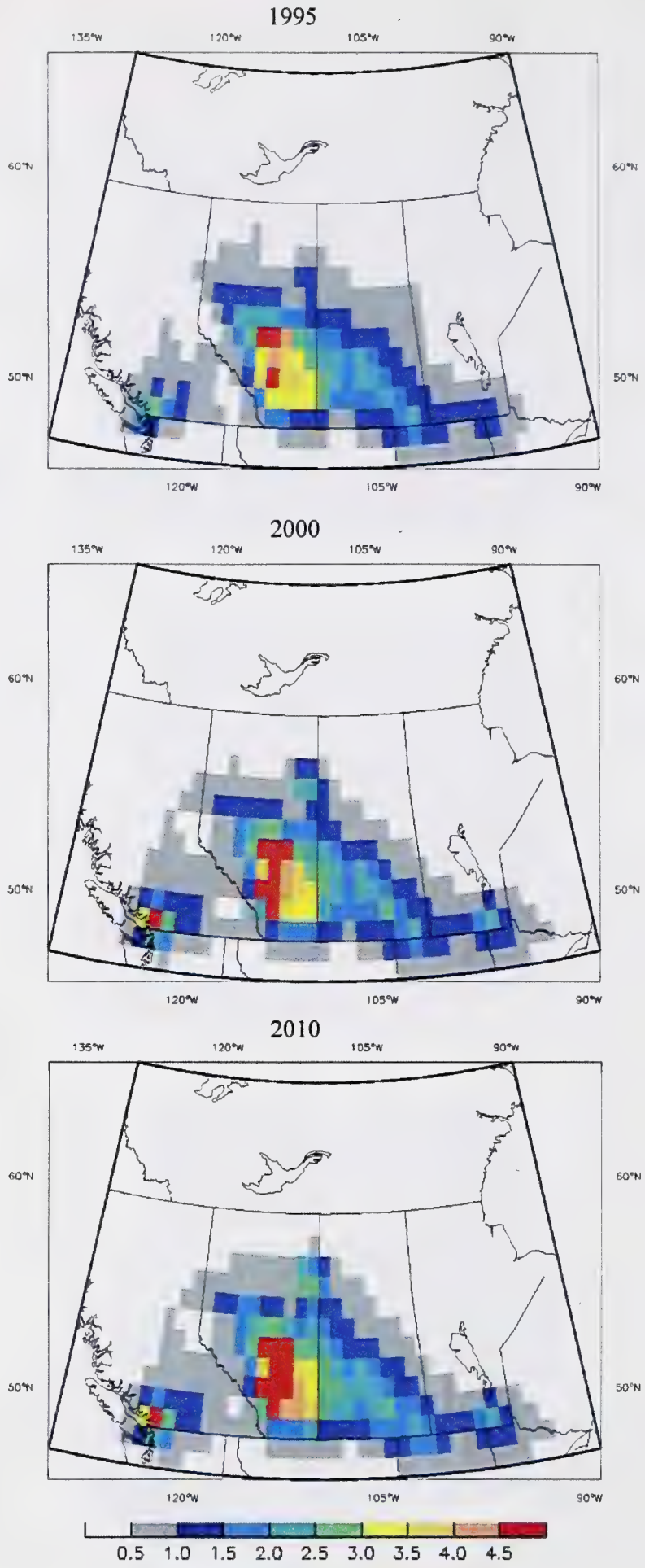

Figure 10 **RELAD results for annual average NO_x concentrations as NO_2 for the years 1995, 2000, and 2010 (projected) ($\mu g\ m^{-3}$).**

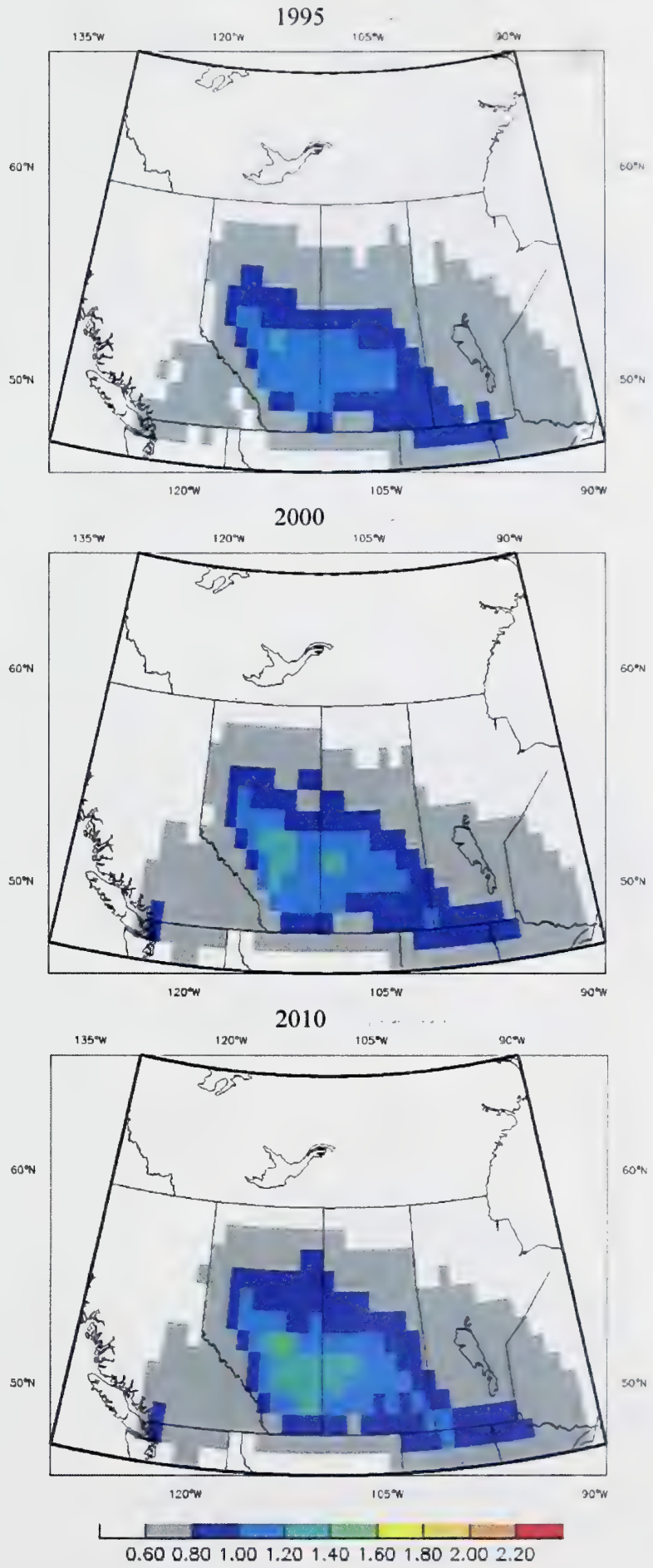

Figure 11 **RELAD results for annual dry deposition of total N for the years 1995, 2000, and 2010 (projected) (kg/ha/yr).**

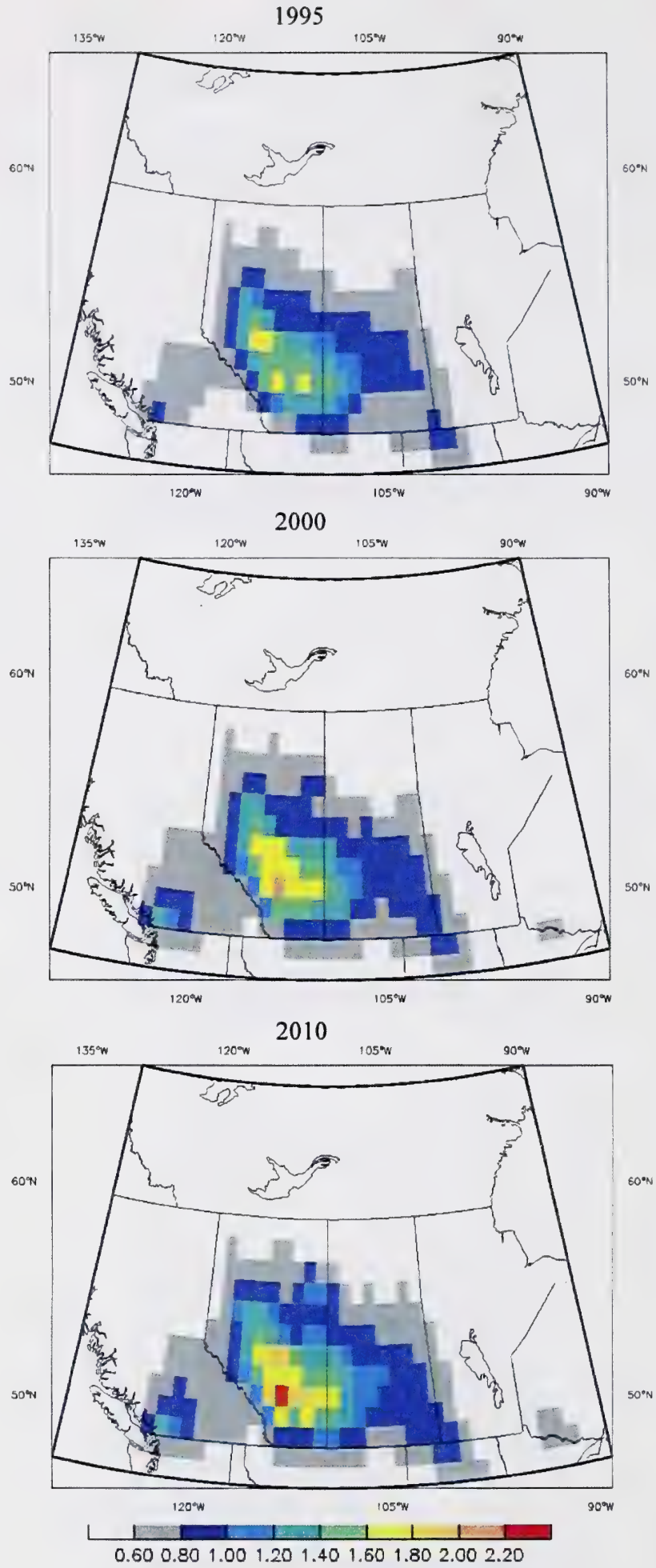

Figure 12 **RELAD results for annual wet deposition of total N for the years 1995, 2000, and 2010 (projected) (kg/ha/yr).**

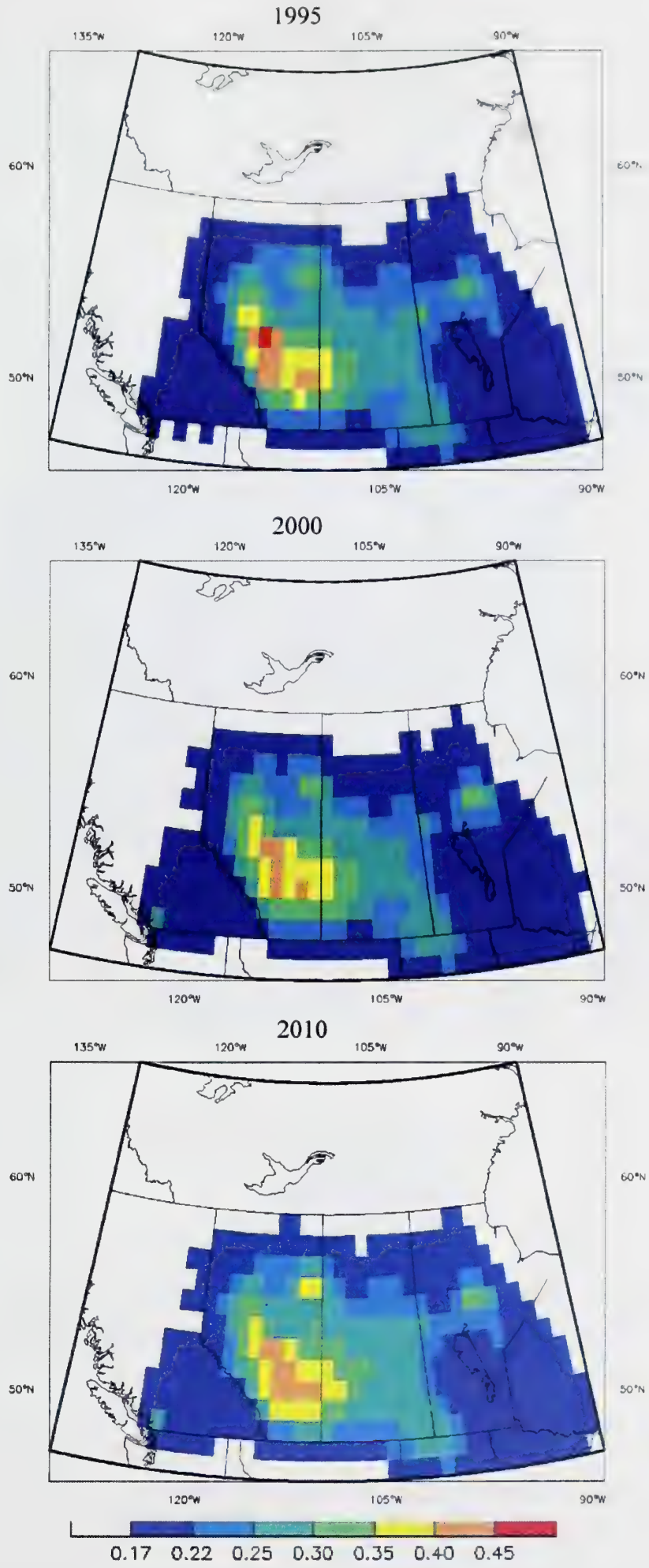

Figure 13 **RELAD results for annual deposition of total S and N for the years 1995, 2000, and 2010 (projected) (kg/ha/yr).**

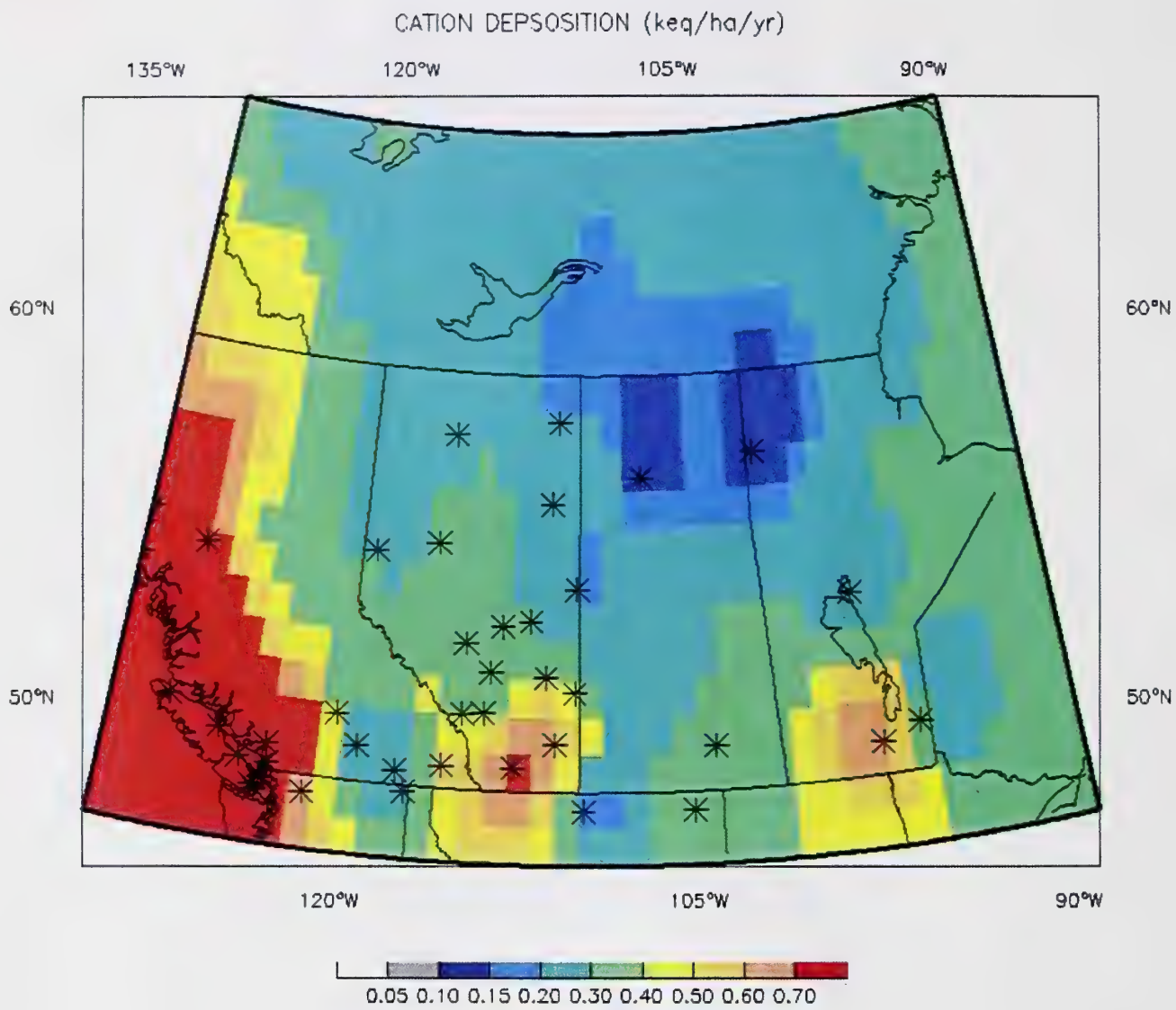

Figure 14 Composite base cation deposition (keq/ha/yr) interpolated from existing monitoring data, where ж denotes locations of precipitation quality monitoring stations.

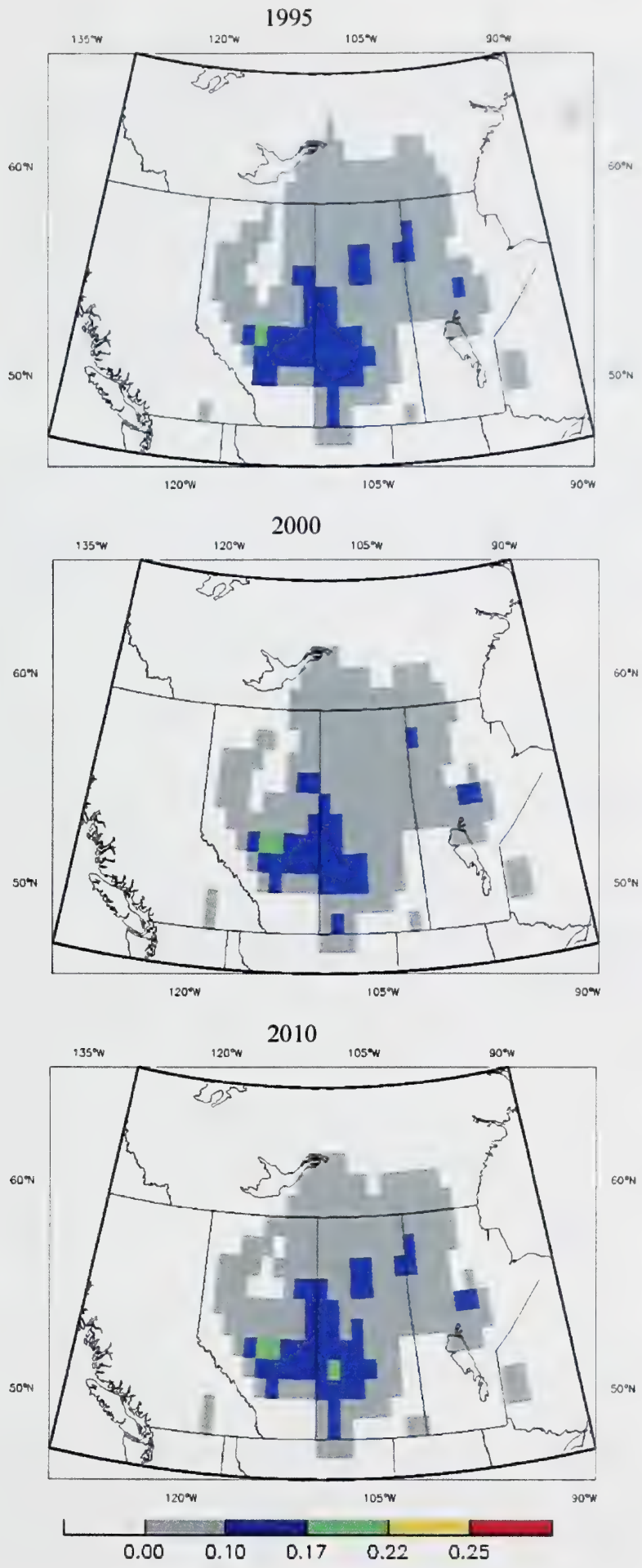

Figure 15 RELAD results for annual PAI for the years 1995, 2000, and 2010 (projected) (keq H^+/ha/yr).

3.0 EVALUATION OF MODEL PREDICTIONS

Monitoring stations have been measuring wet deposition and parameters for predicting dry deposition of acidic pollutants at selected sites in Alberta. Dry deposition is difficult to measure directly and its measurement methods are an active area of research. Measurement of meteorological parameters and atmospheric concentrations of acidic pollutants, and parameterization of the rate of transfer of the pollutants from the atmosphere to a surface using a deposition velocity, is a commonly used method for predicting dry deposition.

Measurement data from the monitoring stations in Alberta can be used to estimate total PAI to get a more accurate picture of acid deposition at these locations. Selected data components that represent long-term averages can be used to make comparisons to regional acid deposition model predictions. In addition, a number of field studies were conducted in Alberta during the past five years examining soil and surface water quality in relation to exposure to acid deposition.

3.1 Wet and Dry Deposition Measurement Data for Alberta

3.1.1 Wet Deposition Measurement Data

Alberta Environment operates a network of nine, wet deposition, monitoring stations throughout Alberta. Wet deposition monitoring data from these stations were received from the Alberta Environment. These data were for the period 2000 to 2004 from monitoring stations located in the following communities (Figure 16):

- Beaverlodge
- Calgary
- Fort Chipewyan
- Fort Vermillion
- Red Deer
- Cold Lake
- Fort McMurray
- Kananaskis
- Suffield

These data contained values for precipitation depth and chemical concentrations from the analysis of precipitation for the following chemicals: NH_4^+, NO_3^-, SO_4^{2-}, Ca^{2+}, K^+, Mg^{2+}, and Na^+. Potential Acid Input from wet deposition (PAI_{wet}) was calculated using the following equation (Cheng *et al.*, 2001):

$$PAI_{wet} = 2\frac{[SO_4^{2-}]}{96} + \frac{[NO_3^-]}{62} + \frac{[NH_4^+]}{18} - \left(\frac{[K^+]}{39} + \frac{[Na^+]}{23} + 2\frac{[Ca^{2+}]}{40} + 2\frac{[Mg^{2+}]}{24}\right) \text{ [keq } H^+/\text{ha/yr]} \quad (1)$$

(where [X] represents the concentration of species X in units of kg species/ha/yr)

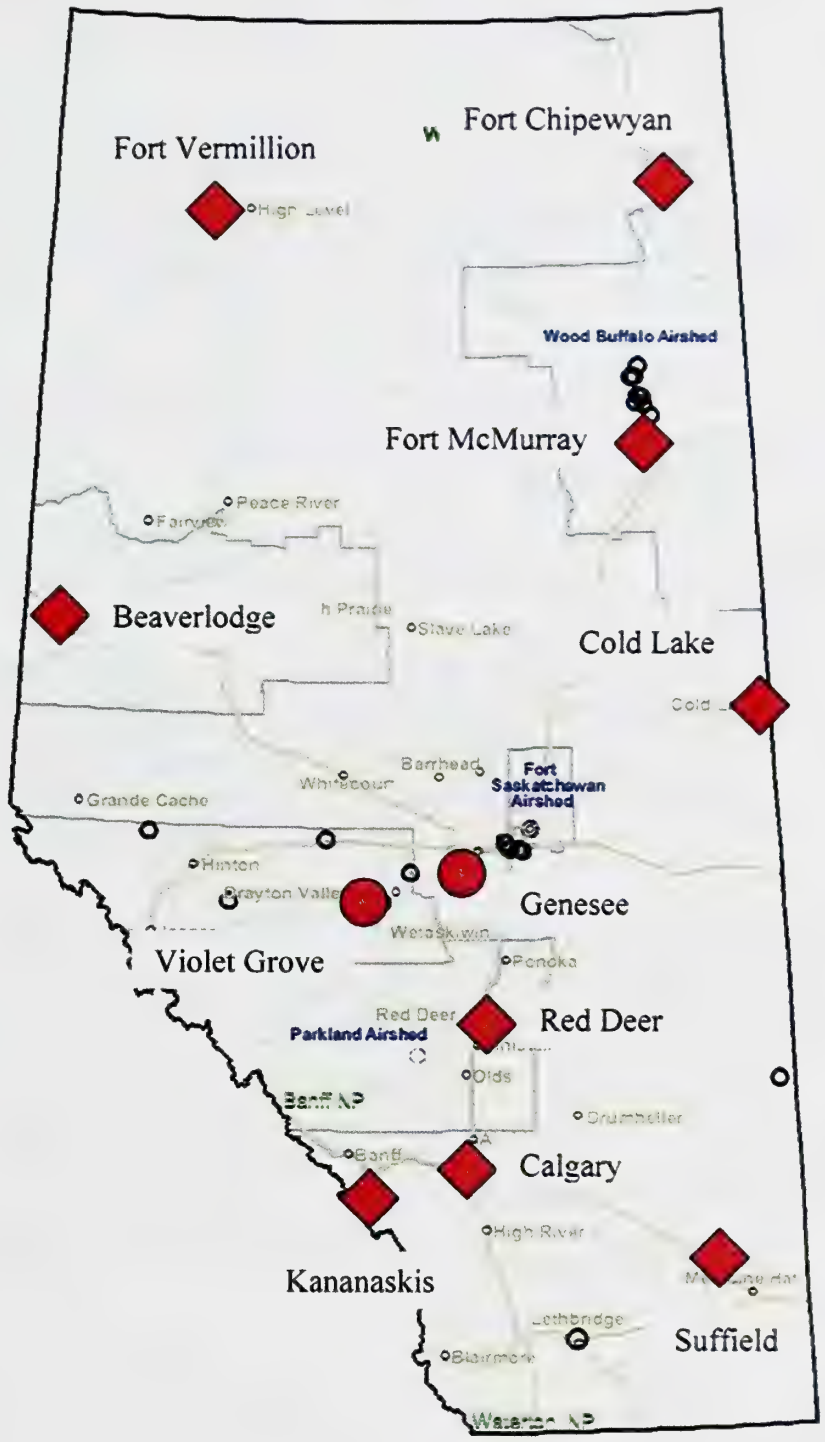

Figure 16 **Wet deposition monitoring stations operated in Alberta**

(♦ denotes location of AENV stations; ● denotes location of WCAS stations).

The contribution of each species to PAI_{wet} was obtained by dividing the annual deposition of each species by its molecular weight and multiplying by the number of possible hydrogen (H^+) ions that can be associated with the species. Values from weekly or bi-weekly integrated samples were summed for each calendar year for each station. Values for periods that spanned the year-end were proportioned to each year based on the number of days between measurements for the period in which the end of the year occurred. Results for the nine Alberta Environment stations are presented in Table 2.

TransAlta Utilities and EPCOR Generation Inc. operate two wet deposition monitoring stations associated with their acid deposition monitoring program in west central Alberta in partnership with the West Central Airshed Society (WCAS)... These stations are the Genesee and Violet Grove air monitoring stations shown in Figure 16 (TAU/EPCOR, 2006). Four coal-fired power plants are located at distances of 8 to 33 km away from the Genesee station. The four power plants are located at distances of 55 to 60 km away from the Violet Grove station. Wet deposition monitoring data for the period 2005 from these stations were reported in TAU/EPCOR (2006) and are reported at PAI in Table 2.

Table 2 Net annual Potential Acid Input from wet deposition (PAI_{wet}) in keq H^+/ha/yr at monitoring stations in Alberta.

Location	2000	2001	2002	2003	2004	2005
Beaverlodge	0.049	0.050	0.051	0.064	0.022	—
Calgary	0.087	0.048	0.073	0.008	0.115	—
Cold Lake	0.061	0.086	0.100	0.090	0.087	—
Fort Chipewyan	—	—	—	—	—	—
Fort McMurray	0.024	0.058	0.042	0.031	0.026	—
Kananaskis	0.023	0.038	0.117	0.076	0.106	—
Fort Vermillion	—	—	-0.139	0.009	0.021	—
Red Deer	0.097*	0.091	0.113	0.132	0.153	—
Suffield	0.039	0.048	0.038	0.017*	0.019*	—
Genesee[1]	—	—	—	—	—	0.10
Violet Grove[1]	—	—	—	—	—	0.0

[1] after TAU/EPCOR (2006)
— not estimated
* incomplete dataset

Wet deposition results were not estimated for Fort Chipewyan (2000 through 2004) or for Fort Vermillion (2000 through 2001) because of numerous missing values in the datasets. Wet deposition monitoring at Red Deer began in April 2000 therefore results presented in Table 2 for the year 2000 do not represent the full year.

An indication of percent completeness of all remaining Alberta Environment monitoring station datasets was assessed using sulphate ion results. Here, percent completeness refers to the percentage of valid data compared to expected data for a complete sampling year. Percent completeness was found to be greater than 90% for all years and locations except for Cold Lake in 2003 (88.6%).

3.1.2 Dry Deposition Measurement Data

Dry deposition in Alberta was estimated for a number of locations (Figure 17) from monitored ambient concentrations of sulphur and nitrogen compounds using the method of Cheng *et al.* (2001):

- Alberta Environmental Protection (AEP) conducted dry deposition and meteorological monitoring at the Royal Park monitoring station, located approximately 15 km northwest of Vegreville (AEP, 1996). Alberta Environmental Protection (AEP, 1996) summarized monthly, seasonal, and annual dry deposition over a 21-month period (October 1992 through to June 1994) at this station.

- Alberta Environment also conducted dry deposition and meteorological monitoring at the Beaverlodge monitoring station located west of Grande Prairie at an Agriculture and Agri-Food Canada Research Farm. Data were collected for a 5-year period 1998 through to the end of 2002 at this station. WBK & Associates (2005) estimated annual dry deposition using these data.

- The Wood Buffalo Environmental Association (WBEA) conducted dry deposition and meteorological monitoring at the Fort McKay air monitoring station – AMS #1 – during 2003. WBK & Associates (2006) estimated annual dry deposition using these data.

- TransAlta Utilities and EPCOR Generation Inc., through WCAS, operate an acid deposition monitoring program (dry deposition and meteorological monitoring) at two stations in the Wabamun-Genesee area of west-central Alberta. Dry deposition monitoring data for the period 2005 were reported for these two stations by TAU/EPCOR (2006).

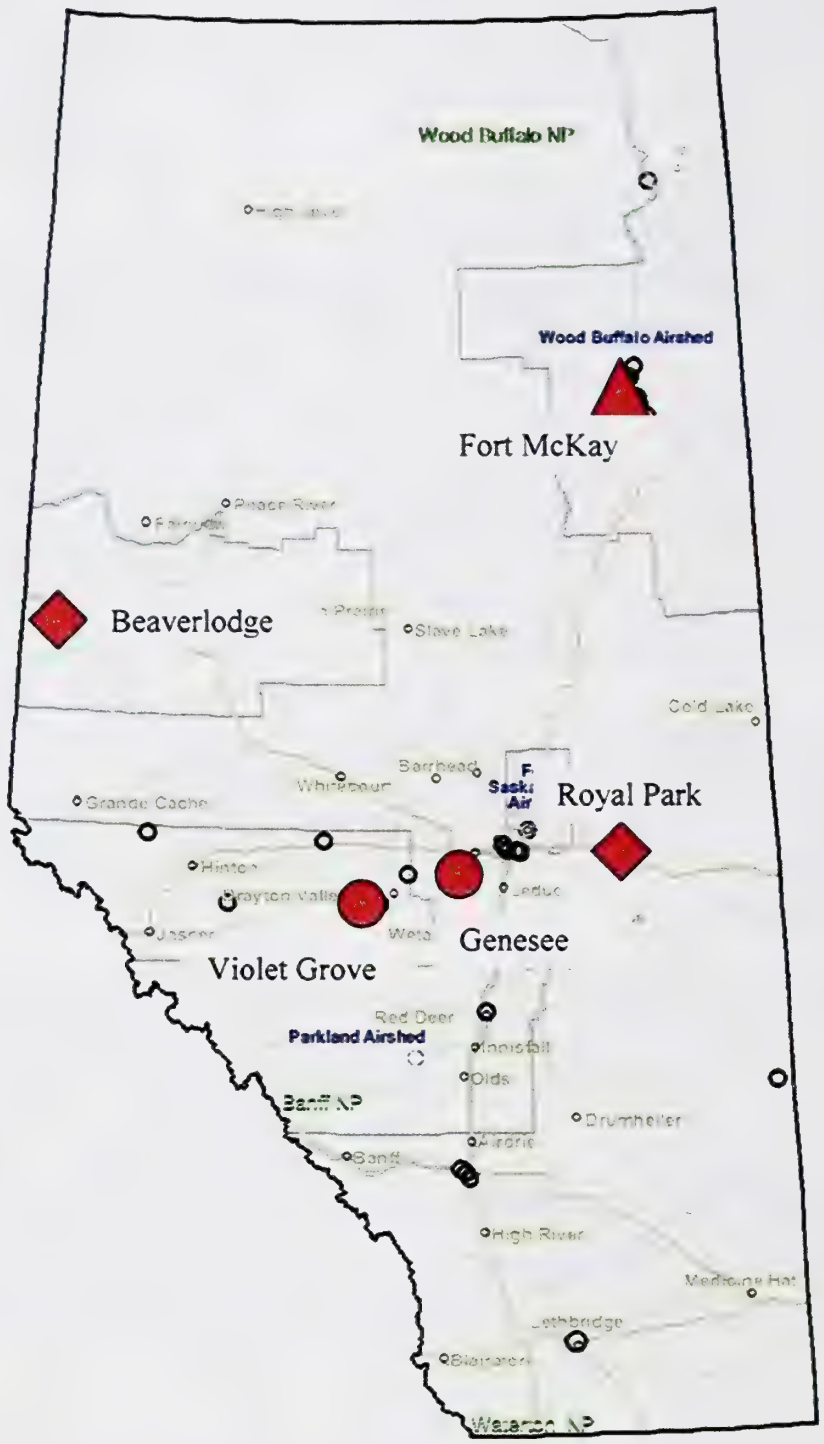

Figure 17 **Dry deposition monitoring stations operated in Alberta**

(♦ denotes location of AENV stations; ● denotes location of WCAS stations; ▲ denotes location of WBEA station).

Potential Acid Input from dry depositing species (PAI_{dry}) was calculated for each of these sites using the following equation (after Cheng *et al.*, 2001):

$$PAI_{dry} = \frac{[SO_2]}{64} + \frac{[NO_2]}{46} + \frac{[HNO_2]}{47} + \frac{[HNO_3]}{63} + 2\frac{[SO_4^{2-}]}{96} + \frac{[NO_3^-]}{62} + \frac{[NH_4^+]}{18} - \left(\frac{[K^+]}{39} + \frac{[Na^+]}{23} + 2\frac{[Ca^{2+}]}{40} + 2\frac{[Mg^{2+}]}{24}\right) \quad [\text{keq } H^+/\text{ha/yr}] \qquad (2)$$

Results are presented in Table 3.

Table 3 Annual Potential Acid Input from dry deposition (PAI_{dry}) in keq H^+/ha/yr at monitoring stations in Alberta.

Location	1993/94	1998	1999	2000	2001	2002	2003	2005
Royal Park[1,a]	0.14	—	—	—	—	—	—	—
Beaverlodge[2]	—	0.093	0.088	0.084	0.10	0.14	—	—
Fort McKay[3]	—	—	—	—	—	—	0.14	—
Genesee[4]	—	—	—	—	—	—	—	0.31
Violet Grove[4]	—	—	—	—	—	—	—	0.21

[1] after AEP (1996)
[2] after WBK (2005)
[3] after WBK (2006)
[4] after TAU/EPCOR (2006)
[a] excludes contribution of NO_x (NO & NO_2)
— not estimated

3.1.3 Potential Acid Input from Wet and Dry Deposition Data

Total Potential Acid Input was estimated for wet and dry deposition at three sites where these data were available (Beaverlodge, Genesee, and Violet Grove, Alberta – refer to Figure 17). The total PAI method involves subtracting base cation deposition (K^+, Na^+, Ca^{2+}, and Mg^{2+}) from deposition of sulphur (SO_2 and SO_4^{2-}) and nitrogen (NO_2, HNO_3, HNO_2, NO_3^-, and NH_4^+) species for wet and dry components:

$$\text{Total PAI} = PAI_{wet} + PAI_{dry} \quad [\text{keq/ha/yr}] \qquad (3)$$

Results are presented in Table 4. The AENV Beaverlodge monitoring station (Figure 17) is located in a grid cell where RELAD model predictions based on year 2000 emissions data indicate average total PAI loadings <<0.1 keq H^+/ha/yr (Figure 18). Whereas total PAI estimated from field measurement data for the years 2000 to 2002 indicate total PAI loadings ranging from 0.13 to 0.19 keq H^+/ha/yr (Table 4).

Table 4 Estimate of Total Potential Acid Input (PAI_{wet} + PAI_{dry}) at selected air monitoring stations in Alberta (keq H^+/ha/yr).

Location	2000	2001	2002	2005
Beaverlodge	0.13	0.16	0.19	—
Genesee	—	—	—	0.41
Violet Grove	—	—	—	0.21

— not estimated

The WCAS Genesee and Violet Grove monitoring stations (Figure 17) are both located in a grid cell where RELAD model predictions based on year 2000 emissions data indicate average total PAI loadings ranging from of 0.17 to 0.22 keq H^+/ha/yr (Figure 18). Whereas, total PAI estimated from field measurement data for the year 2005 indicate total PAI loadings ranging of 0.41 keq H^+/ha/yr (Genesee) and 0.21 keq H^+/ha/yr (Violet Grove) (Table 4).

The comparison of PAI loadings derived from field data to RELAD results has certain limitations. While field data for the three stations indicate higher PAI loadings relative to RELAD results, these data apply to very localized areas while RELAD results represent average PAI loadings over a very large area (1° latitude by 1° longitude or approximately 110 km by 60 km) – approximately 6,660 km^2). In addition, RELAD model results represent average conditions based on long-term time-averaged meteorological conditions while deposition estimates derived from monitoring data represent meteorological and emission conditions for a distinct, shorter time period. As the model and field monitoring programs are not run under exactly the same conditions, they are not directly comparable.

3.1.4 Comparisons to Regional Acid Deposition Model Predictions

RELAD model results were compared to selected time-averaged field monitoring data (SO_2 concentrations, total sulphur wet deposition, and total nitrogen wet deposition) from selected stations. Field data for NO_x were not part of the comparison. Most NO_x measurements are located in population centres with significant sources of NO_x, which are difficult for the RELAD model to simulate. Figure 19 presents monitored versus RELAD modeled annual SO_2 concentrations at selected monitoring sites in Alberta measured from 2001 to 2005 and Saskatchewan (SK) obtained in 2005 using 1995 and 2000 emissions data to run RELAD.

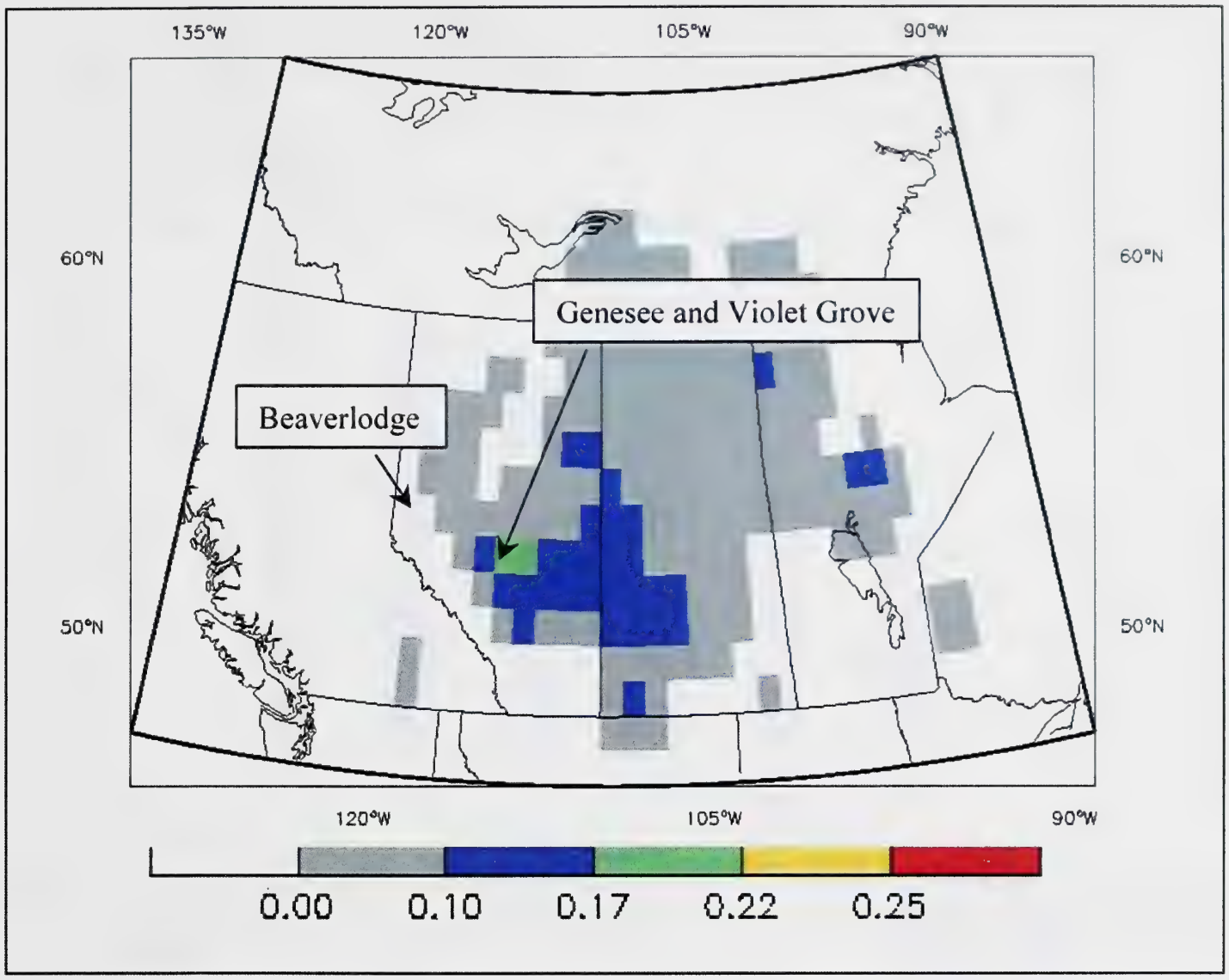

Figure 18 Grid cells containing selected acid deposition monitoring stations in Alberta along with RELAD results for annual PAI (keq H^+/ha/yr) for the year 2000.

Coefficients of determination (R^2) values shown in Figure 19 offer insights about how well a best-fit linearly regressed line represents the data for the model years 1995 and 2000. A high R^2 value indicates that the independent variable, monitored SO_2 concentration in this case, is a good predictor of the dependent variable, RELAD modeled SO_2 concentration. In the case of 2000 data, 78% of the variability in RELAD modeled SO_2 concentrations can be explained by the monitored SO_2 concentrations. The remaining 22% of variability is due to other unexplained factors.

Acidifying precursor emissions can change appreciably from year to year in Alberta. Figure 20 illustrates the temporal variations in annual SO_2 emissions and annual averaged SO_2 concentrations measured in the Parkland Airshed Management Zone (PAMZ) of Alberta using passive samplers. SO_2 emissions and annual average ambient concentration decreased by more than 50% over a 5-yr period (2000 to 2005). With respect to RELAD prediction capabilities, the

model predicts concentrations corresponding to emission loadings. Because the model is not run under conditions representing actual emission conditions, an absolute comparison or evaluation of the model to monitoring results is not possible. Nevertheless, RELAD modeling offers reliable predictions about large area air-concentration patterns and wet-, dry-, and total-deposition patterns of acid forming pollutants corresponding to estimated current and future amounts and geographic distributions of acidifying emissions.

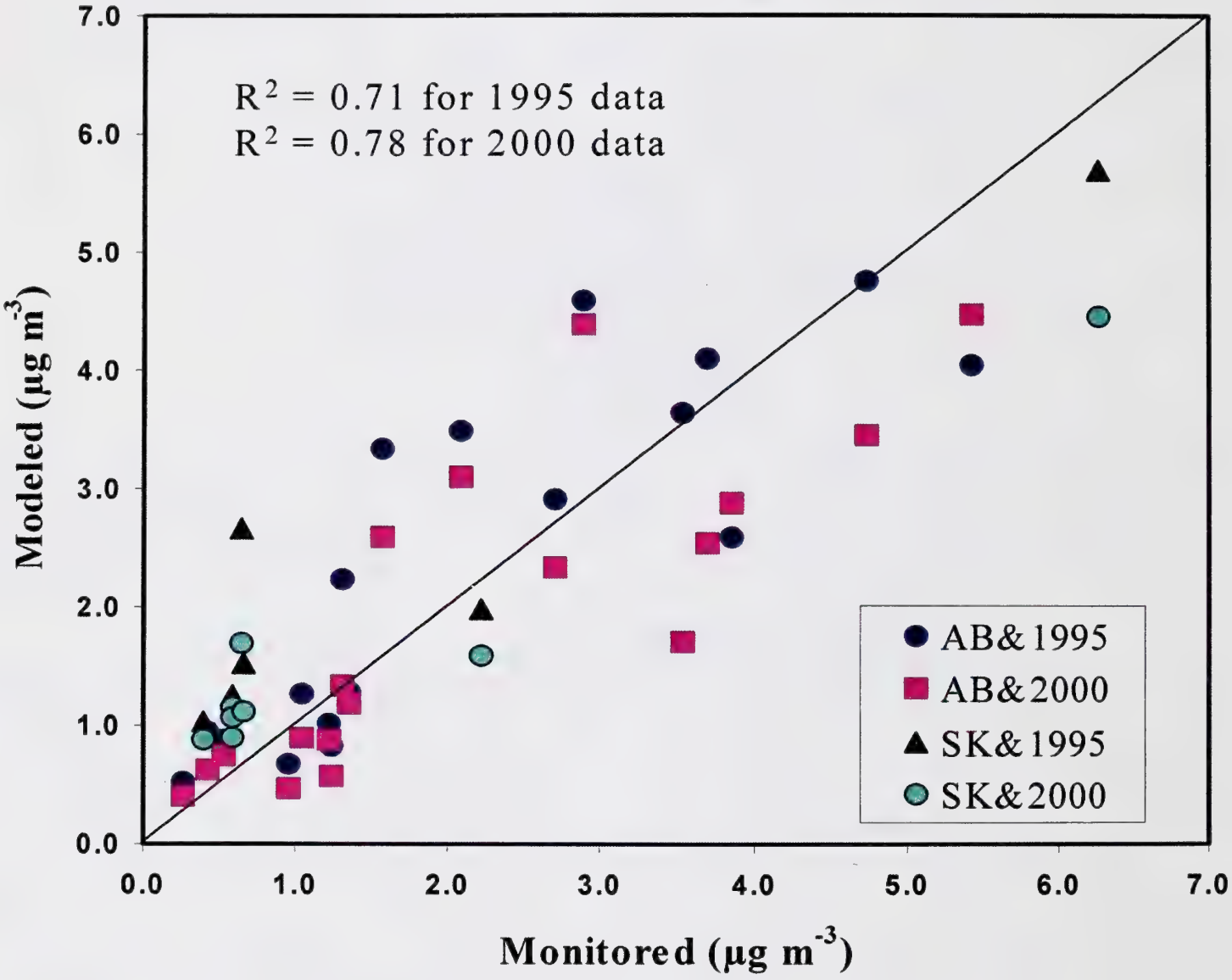

Figure 19 Comparison of monitored versus RELAD modeled annual SO_2 concentrations at selected monitoring sites in Alberta and Saskatchewan using 1995 and 2000 emissions data.

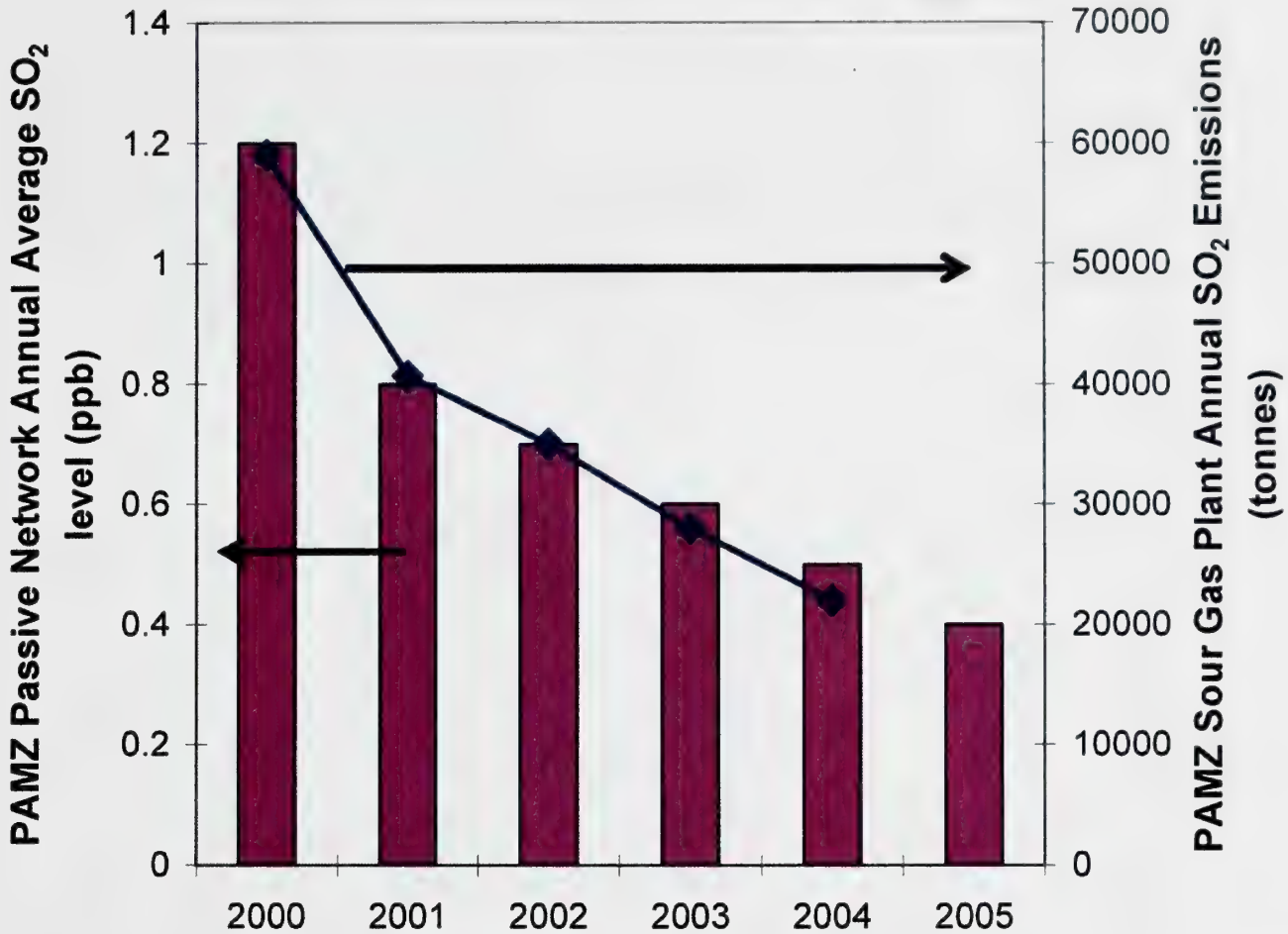

Figure 20 Parkland Airshed Management Zone passive air monitoring network annual average ambient SO_2 levels and total sour gas plant emissions of SO_2 (2000 to 2005)

(bars refer to SO_2 level, diamonds refer to SO_2 emission quantities).

Figures 21 (and 22) presents monitored versus RELAD modeled annual wet sulphur deposition and annual wet nitrogen deposition results at selected monitoring sites in Alberta using 1995 and 2000 emissions data. Data from 2000 to 2004, and 2005 were not available at the time of this study.

R^2 values shown in Figure 21 indicate that only about 50% of the variability in RELAD annual wet sulphur deposition can be explained by monitored wet sulphur deposition data; whereas, the remaining 50% of variability is attributed to other unexplained factors. R^2 values shown in Figure 22 indicates that about 70% of the variability in RELAD annual wet nitrogen deposition can be explained by the monitored wet nitrogen deposition; whereas, the remaining 30% of variability is attributed to other unexplained factors.

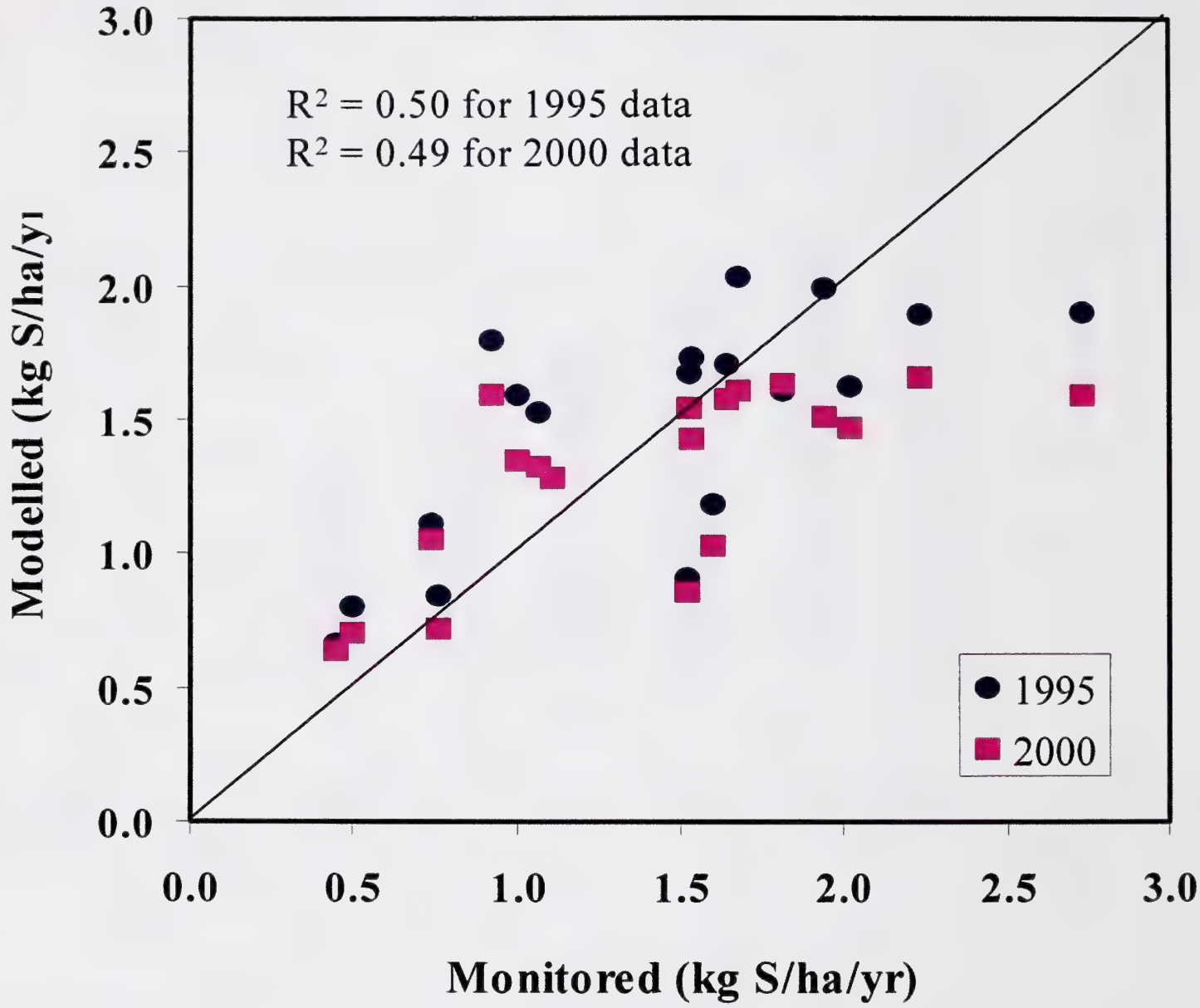

Figure 21 Comparison of monitored versus RELAD modeled annual wet sulphur deposition at selected monitoring sites in Alberta using 1995 and 2000 emissions data.

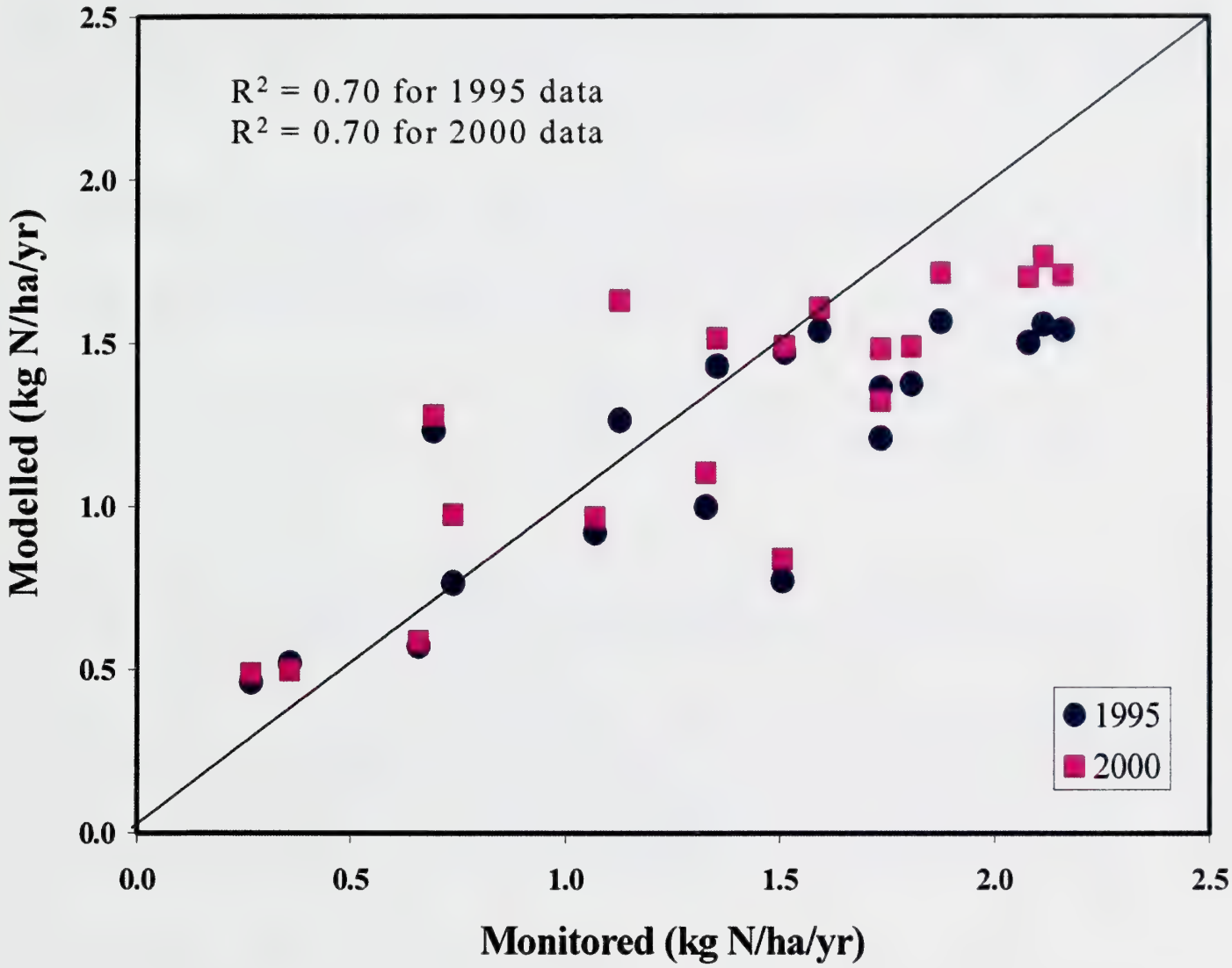

Figure 22 Comparison of monitored versus RELAD modeled annual wet nitrogen deposition at selected monitoring sites in Alberta using 1995 and 2000 emissions data.

3.2 Field Studies of Soil and Surface Water Quality in Relation to Acid Deposition in Alberta

Soil and surface water act as primary receptors to acid deposition. The current state of soil and surface water quality is important for understanding potential relationships to exposure to acid deposition. Four field studies were undertaken in Alberta during the past five years relating to soil and surface water quality:

- Properties of Sensitive Soils (CEMA, 2005).
- Critical Loads of Acidity to Lakes in the Athabasca Oil Sands Region – Modification of the Henriksen Model for Lake Organic Content (NSMWG, 2006).
- Site-Specific Critical Loads of Acid Deposition on Soils in the Provost-Esther Area, Alberta (AENV, 2001).
- Terrestrial Environmental Effects Monitoring Acidification Monitoring Program – 2004 Sampling Event Report For Soils, Lichen, Understory Vegetation and Forest Health and Productivity (TEEM, 2006).

3.2.1 Sensitivity Categories of Soil and Water to Incoming Acidic Deposition

Soils and water are closely linked in a catchment area because runoff and groundwater flow are affected by the chemical properties of soils through which water percolates. Vegetation is often ignored as a receptor because the effects of acid deposition on vegetation are slow to develop, difficult to measure, and difficult to evaluate as compared to effects on soil and water. In Alberta, receptors are divided into three categories: mineral soils, organic soils, and water (AENV, 1999).

3.2.1.1 Mineral Soils

The sensitivity of mineral soils is categorized on the basis of pH and cation exchange capacity (CEC). Holowaychuk and Fessenden (1987) developed low, medium, and high sensitivity categories for relative base loss, acidification, and aluminum solubilization (Table IV.1, Appendix IV).

3.2.1.2 Organic Soils

Organic soils differ from mineral soils in that they contain 30% or more of organic material. Organic soils have been categorized by the peatland systems of eutrophic, mesotrophic, and oligotrophic on the basis of chemical properties of soils and associated pool waters by Holowaychuk and Fessenden (1987) (Table IV.2, Appendix IV). Low, medium, and high sensitivity categories have been developed for relative base loss, acidification, and aluminum

solubilization for these three peatland systems by Holowaychuk and Fessenden (1987) (Table IV.3, Appendix IV).

In Alberta, the most extensive category is the mesotrophic/moderate rich fen. Kuhry *et al.* (1993) expressed concern that acidification of a rich fen could cause or accelerate its transition to a nutrient deficient bog by virtue of selection for acid-producing *Sphagnum* mosses. Re-evaluation of the organic soil sensitivity ratings was undertaken in the 1990s. Previous work undertaken for the Target Loading Subgroup of the Clean Air Strategic Alliance (Turchenek *et al.*, 1998) recommended changes to sensitivity ratings for several peatland systems. This included:

- Moving the oligotrophic/bog and poor fen from a low to a medium sensitivity rating.
- Moving the mesotrophic/moderate rich fen from a high to a low sensitivity rating.
- Placing the eutrophic/extreme rich fen into the low sensitivity rating category.

In the end, the Target Loading Subgroup decided that the sensitivity categorizations of Holowaychuk and Fessenden (1987) would remain unchanged. A map of overall sensitivity rating for soils in Alberta can be found in AENV (1999).

The Cumulative Environmental Management Association (2005) assessed existing soil data from the Athabasca Oil Sands Environmental Research Program (AOSERP) to determine if these data were adequate for use in predictive soils effects models to model change over time. Three main tasks were completed as part of the assessment:

- Compilation of a soils database.
- Evaluation of the database to assess if it was sufficient for use in a number of predictive soils effects models (e.g., ARC, MAGIC, SMART, VSD, and SMART2).
- Development of recommendations for the structure of a field program..

A database of seven sensitive soils, as defined by Holowaycuk and Fessenden (1987), was compiled from twenty-two published reports (CEMA, 2005). The database was evaluated to assess the adequacy of existing sample size, variability, confidence limits for soil properties, spatial distribution of existing sample sites, and the basis for sample site selection. Existing sample sites were plotted on a map of sensitive soil series in the region.

Evaluation of the database yielded a number of findings (CEMA, 2005). Statistics for pH, cation exchange capacity (CEC), and base saturation percentage were calculated. Variability and confidence limits were observed to be higher for exchangeable base saturation percentage and cation exchange capacity and lower for pH.

For horizons of different thickness, properties for mineral soils were standardized to 25 cm for use in the ARC model. Consequently, it was found that it would be difficult to confidently run the models because of problems with excessive variability in the data (CEMA, 2005). The VSD and the ARC models were found to require verification although it was stated that this would be difficult to attain because of the lack of historical data. It was recommended that one inspection, considering both leaf litter and mineral soil layers, be done for every 100 hectare of a soil

polygon using the transect approach with consideration given to modeled PAI isopleths in the region.

3.2.1.3 Water

Lake sensitivity in the Athabasca region of Alberta was evaluated by NSMWG (2006) using alkalinity as it was reported by Erickson (1987) to be the most accurate variable for assessment of aquatic sensitivity to acid deposition. Alkalinity is commonly used as a measure of inorganic buffering from the presence of carbonate and bicarbonate anions. The sensitivity rating system for water is shown in Table IV.4 (Appendix IV) (Erickson, 1987).

Critical loads of acidity for 399 lakes were re-calculated by NSMWG (2006) using a Henriksen steady state model with the addition of adjustments for strong organic acids and weak organic acids. A primary purpose of the work by NSMWG (2006) was to address a bicarbonate assumption of the Henriksen steady state model in which carbonate and bicarbonate were assumed to be the only sources of buffering. High levels of dissolved organic carbon (DOC) – which include strong and weak organic acids – were believed to affect acid and buffering levels of waters such that it was a concern that the Henriksen model would not represent chemistry of waters in the Athabasca region. DOC values used in the model were developed using results from 66 of the original 399 lakes.

NSMWG (2006) determined that in low-pH/low-acid neutralizing capacity (ANC) lakes, the amount of organic buffering was small (less than 20 μeq/L) although it represented a large proportion of the total buffering (greater than 80%). NSMWG (2006) determined that organic buffering was large (greater than 200 μeq/L) in high-pH/high-ANC lakes; but it only represented a small part of the overall buffering (less than 20%).

Critical loads for acidity were re-calculated to examine how much impact and whether certain lakes were more likely to have changes in their critical values based on adjusting the Henriksen model for organic acids, both weak and strong (NSMWG, 2006). The impact of including organic buffering and strong organic acids into the Henriksen model was that critical loads for 187 lakes increased, while critical loads for 212 lakes decreased. The median change was a decrease of 0.0054 keq H^+/ha/yr, while change in the mode was an increase of 0.0130 keq H^+/ha/yr (NSMWG, 2006).

Maps showing lakes in exceedance for the different scenarios can be found in NSMWG (2006). The assessment found that there was an overall increase in critical load in high-pH lakes and a decrease in low-pH lakes, as compared to the previous assessment. The previous assessment did not consider organic buffering and acidity. Of 399 lakes for which sufficient data were available within the assessment area, 367 (or 92%) had a critical load less than 0.25 keq H^+/ha/yr and 32 (or 8%) had a critical load greater than 0.25 keq H^+/ha/yr based on acid deposition loading corresponding to a future cumulative effects emissions scenario. These findings suggest that the approach of using subsoil sensitivity as a surrogate for lake sensitivity and/or using 0.25 keq H^+/ha/yr as the critical load for highly sensitive lakes may need to be re-considered.

3.2.2 Potential of Soil and Water to Reduce Acidity of Incoming Acidic Deposition

The potential ability of soil and geology to reduce acid input differs from soil sensitivity in that subsoil materials below the "20-cm horizon for soil sensitivity assignments" can act to affect the ability of soil to reduce acidity of incoming acidic deposition (AENV, 1999). The potential ability of soil and geology to reduce acid input is of interest because most water in a lake or pond originates from precipitation that travels through soil in a catchment area, dissolving chemicals from soil as it travels. The amount and nature of chemicals that become dissolved in runoff also depends upon the chemical and physical nature of runoff as it passes through soil.

The Target Loading Subgroup of the Clean Air Strategic Alliance decided that sensitivity of provincial waters would be best represented by the ability of surrounding soils to reduce acid input (AENV, 1999). The logic was based on the fact that buffering ability of soils is typically passed onto lakes by virtue of runoff from precipitation percolating through soils. While not true for every situation, AENV (1999) reported that there was a close correlation between the location of sensitive lakes and the ability of regional soil to reduce acid input. Further information on sensitive lakes and the ability of regional soil to reduce acid input in Alberta can be found in AENV (1999).

3.2.3 Overall Receptor Sensitivity Assignments for Soil and Water

Final assignments of receptor sensitivity for the purpose of loading calculations in Alberta were done by AENV (1999) using a more sensitive classification of the combination of soil sensitivity and the ability to reduce acid input at a soil unit level. The province was divided into the same grid cells as were used for the RELAD model. Assignments for each grid were done by AENV (1999) based on the proportion of the grid that was sensitive or moderately sensitive as shown in Table IV.5 (Appendix IV).

An effects-based system was designed in Alberta to include a "monitoring load" (AENV, 1999). A monitoring load is a level that when reached requires that further monitoring and research activities be performed. The reason that it was desirable to include this type of load in the Alberta system is that there was (and still is) a paucity of acid deposition data (AENV, 1999). There are also large gaps in scientific knowledge regarding acid deposition, particularly in the area of organic soils (peatlands).

Original designations for critical loads were assigned based on what was known at the time (AENV, 1999). In order to compromise for lack of data and scientific knowledge, monitoring loads were created so that there would be sufficient time such that any errors associated with shortcomings in the original assignments could be addressed before target loads are reached (AENV, 1999). Alberta Environment (1999) reported that a benefit of using monitoring loads is that resources can be concentrated in areas of the province where acid deposition may be an environmental issue, rather than embarking upon an extensive and expensive, province-wide monitoring program.

3.2.4 Reassessment of Receptor Sensitivity for Provost-Esther Grid Cell

The benefit of the above-described process was demonstrated for a grid cell located in the Provost-Esther area of Alberta (located at 51.5 to 52.5° latitude and 109.5° to 110.5° longitude) (AENV, 2001). Original RELAD modeling of acid deposition in the Provost-Esther grid cell (AENV, 1999) reported PAI loadings (0.18 keq H^+/ha/yr) in excess of the monitoring load of 0.17 keq H^+/ha/yr.

The normal protocol for any grid cell where the monitoring level is exceeded is that the area be reassessed in order to determine whether the original designation was accurate and appropriate (AENV, 1999). The Provost-Esther area grid cell was originally classified as having high receptor sensitivity to acid deposition by AENV (1999) as a result of having sensitive soil in more than 5% of the grid cell. The AENV (2001) reassessment had two objectives: (1) to develop a methodology for determining and assigning receptor sensitivity considering land uses, aquatic systems, soil and water samples, and receptor models; and (2) to apply the methodology to re-estimate critical load for the Provost-Esther area grid cell.

The first issue addressed by AENV (2001) was sampling and mapping of the Provost-Esther area for soil types, land uses, and water systems. It was determined by AENV (2001) that it was unnecessary to sample agricultural land because the use of fertilizers would mask any impact from acid deposition, producing meaningless results. Water systems in the area were found by AENV (2001) to be saline and therefore considered to be insensitive to acid deposition.

AENV (1999) divided the cell grid region up into "land systems" used by the CAESA Soil Inventory Working Group – which was defined as a 'general pattern of land surface form, surficial geologic materials, amount of lakes or wetlands, or general soil pattern' (CAESA Soil Inventory Working Group (1998) as cited in AENV, 2001). For the purpose of soil classification for sensitivity ratings, a "land system" was the smallest workable mapping size unit. AENV (2001) stated that information at the land system level is at a greater level of detail than land units used in the Holowaychuk and Fessenden (1987) sensitivity rating system.

Dominant and subdominant soil series and the extent of each were determined for each land system from AGRASID information (AENV, 2001). Soils series were assigned preliminary sensitivity ratings by AENV (2001) based on texture alone (refer to Table IV.6, Appendix IV), because texture could be frequently and reliably estimated in the field, whereas chemistry could not. The purpose of the preliminary classification was to allow elimination of low sensitivity soils from the sampling procedure thereby allowing resources to be focused on areas of real concern with regards to acid deposition. As well, soils in the low sensitivity range tended to be cultivated, thereby having a higher nutrient content and buffering capacity by virtue of higher base cations.

It was determined by AENV (2001) that based on the assigned preliminary sensitivity ratings, there were four land systems that were potentially sensitive and three land systems that were potentially moderately sensitive. The sensitive and moderately sensitive, dominant and subdominant soil series for each land system were sampled down to a 50-cm depth and chemically analyzed for (AENV, 2001): pH ($CaCl_2$); pH (H_20); Calcium Carbonate Equivalent;

total carbon, nitrogen, and sulphur; Cation Exchange Capacity (Neutral Salt); Cation Exchange Capacity (Buffered); Exchangeable Ions; and Electrical Conductivity and soluble salts. AGRASID data base values were used to represent chemistry of low sensitivity soils.

Critical load values for twelve soils were estimated by AENV (2001) using four different models:

- An empirical model.
- A steady state mass balance model (SMB) (Sverdrup and De Vries, 1994 as cited in AENV, 2001)).
- An Alberta Research Council (ARC) model (Abboud and Turchenek, 1990 as cited in AENV, 2001).
- A Simulation Model for Acidification's Regional Trends (SMART) (de Vries as cited in AENV, 2001).

It was determined by AENV (2001) that the ARC and the SMART models were more realistic because they addressed the simulation of soil chemistry by virtue of cation exchange buffering properties as opposed to the SMB and empirical method which addressed only weathering and plant retention of cations without cation exchange buffering. The ARC and SMART models were run for each soil site to generate 50- and 100-year critical levels of acid deposition that would result in reaching critical loads. AENV (2001) defined critical load in three different ways: as causing a 20% reduction in base saturation percentage; a pH($CaCl_2$) decrease to 5.0; or a base cation to aluminum ratio in soil solution of 45.

Alberta Environment (2001) found that the most protective variable limiting the level of acid deposition was the 100-year critical level for base saturation when tested using the ARC model. This was also the most restrictive variable for the SMART model. Base saturation percentages were found to be lower for the SMART model, but these were discounted by AENV (2001) as unreliable because of problems with model results being low in all instances. A recommendation was made by AENV (2001) to use critical limits from the ARC model for both 50- and 100-years as shown in Table IV.7 (Appendix IV) to determine critical load values.

Land systems for the Provost-Esther area grid cell were evaluated for sensitivities based on the 25th percentile threshold with adjustments for water and cultivated land. Alberta Environment (2001) recommended that the 25th percentile be used as a representative value for the distribution of sensitivity ratings. Alberta Environment (2001) found that 18.7% of the Provost-Esther area grid cell was moderately sensitive with the rest having low sensitivity. As a result, AENV (2001) recommended that classification of the Provost-Esther area grid cell be changed from "high sensitivity" to "moderate sensitivity."

3.2.5 Investigation of Acid Deposition Inputs and Soil/Forest Chemistry for Jack Pine Forests in Wood Buffalo Region

The Terrestrial Environmental Effects Monitoring Committee (2006) examined acid deposition variables in soil and vegetation at 10 to 13 sites in jack pine forests in the Wood Buffalo region

of Alberta. Soil was sampled at three or four depths: leaf litter, 0 to 5 cm, 5 to 15 cm, and 15 to 30 cm for the throughfall zone; and leaf litter, 0 to 5 cm, and 5 to 15 cm for the freefall zones at each site.

Samples were analyzed for pH ($CaCl_2$), total sulphur (S), cation exchange capacity (CEC), exchangeable ions, electrical conductivity (EC) in soil solution, and soluble ions in soil solution. Leaf litter and the top two layers were also analyzed for nitrogen (N) and carbon (C). Selected species of lichen were analyzed for elemental concentrations and measured for vigour variables. Jack pine stand health, needle retention and condition, and analysis of needle tissue were evaluated at the sites.

Levels of PAI were predicted for the sites using the CALPUFF model and were found by TEEM (2006) to be correlated with total sulphur content in the leaf litter layer, but not in the 0 to 5 cm or 5 to 15 cm layers. TEEM (2006) also reported that predicted deposition levels were not related to pH, base saturation percentage, or base cation:aluminum ratio.

For the lichen analyses, TEEM (2006) found relationships for both species of lichen studied between predicted deposition levels and nitrogen, sulphur, aluminum, arsenic, chromium, cobalt, molybdenum, sodium, and vanadium. For conifer foliar tissue; total sulphur, inorganic sulphur, iron, and nickel were found to have a relationship with predicted deposition. There was no evidence of reduced productivity or vigour for lichen or conifer foliar materials.

Key conclusions of the TEEM (2006) report included:

- No statistically significant relationship was identified between predicted deposition levels and key soils parameters, including pH, base saturation, and base cation:aluminum (BC:Al) ratio.
- Statistically significant positive relationships were observed between deposition levels and elemental concentrations in analyzed materials. Specifically, positive relationships were found between:
    1. Sulphur and soils, lichen and conifer foliage.
    2. Nitrogen, iron, and nickel and lichen and conifer foliage.
    3. Aluminum, arsenic, chromium, cobalt, copper, molybdenum, sodium, strontium, titanium and vanadium and lichen.
- Despite observing significant increases in elemental concentrations in soils, lichen, and conifer foliage materials with predicted increasing deposition of industrial emissions, no significant impacts on ecosystem health or productivity were conclusively documented. Lichen vigour variables showed no significant effect in relation to predicted deposition, and forest productivity data showed a possible (positive) effect, which may be due to confounding factors unrelated to industrial emissions.

4.0 UPDATE OF RECEPTOR SENSITIVITY FOR ALBERTA

Alberta Environment's ADAG revised the receptor sensitivity map for the RELAD grid system originally developed for Alberta by AENV (1999). AENV (1999) indicated that new receptor sensitivity data can originate from a variety of sources including, but not limited to: environmental impact assessments (EIAs) conducted for new facilities, monitoring programs of ecological and biological effects on the environment, sampling surveys, and research studies.

Alberta Environment (1999) originally recommended that any new assessment, based on a five-year cycle, predicting grid cells with a level of acid deposition higher than the monitoring load should be evaluated for their receptor sensitivity. Based on work by AENV (2001), new receptor sensitivity data indicated that the Provost-Esther area grid cell and an adjacent grid cell should be changed from "high sensitivity" to "moderate sensitivity." This change is reflected in Figure 22, showing a revised receptor sensitivity map for Alberta.

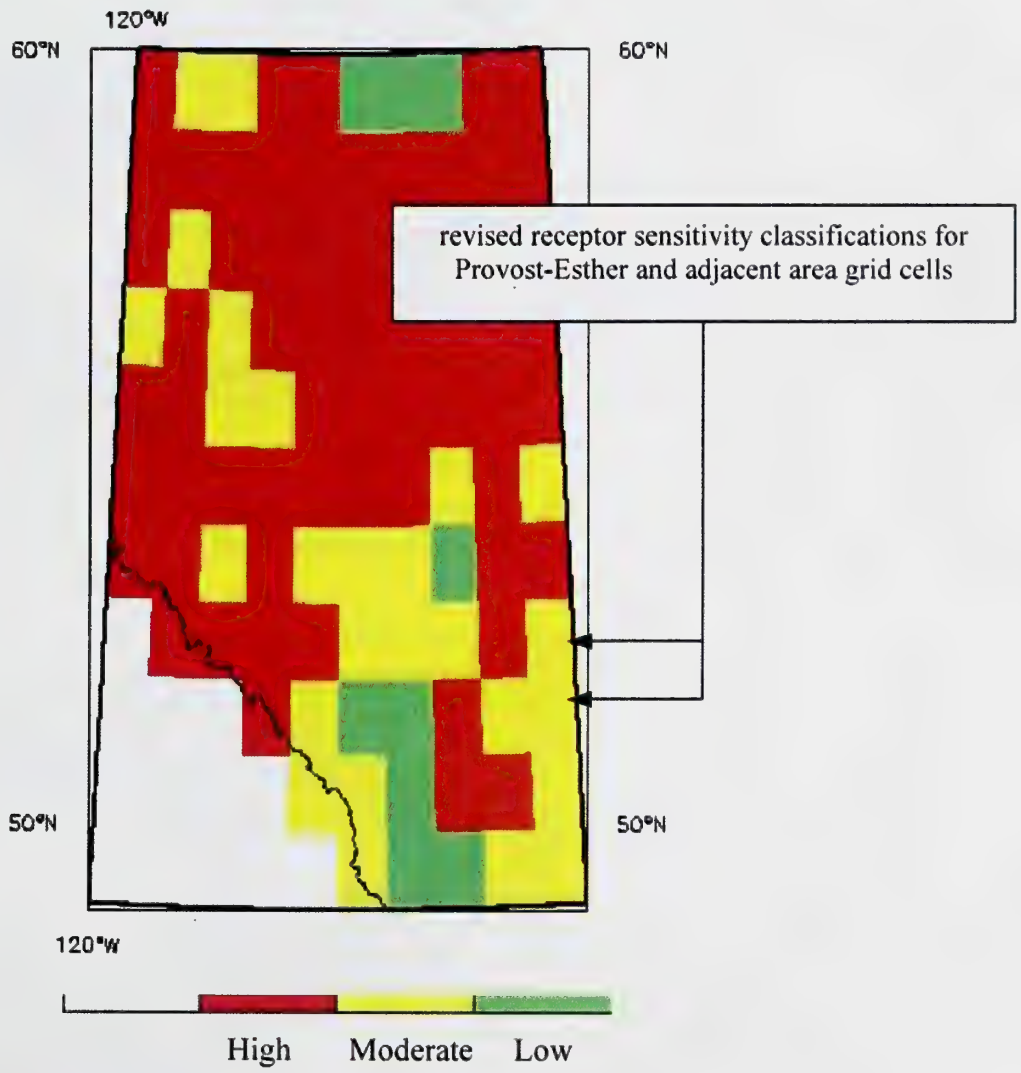

Figure 23 Revised receptor sensitivity map based on work of the Alberta Environment ADAG.

5.0 COMPARISON OF MODELED DEPOSITION TO RECEPTOR SENSITIVITY

Comparison of RELAD modeled PAI to receptor sensitivity for each grid cell is accomplished by estimation of amount of acid deposition as percentage of critical, target, and monitoring loads developed by AENV (1999). Critical loads for Alberta were set at 0.25, 0.50, and 1.0 keq/ha/yr for sensitive, moderately sensitive, and low sensitivity soils, respectively by AENV (1999).

Critical loads are aimed at protecting ecosystems from acid deposition. According to an effects-based management approach towards managing acid deposition, critical loads are established to represent levels of acid deposition that can be sustained and will not cause long-term adverse effects on the ecosystem (AENV, 1999).

Target loads for Alberta were set at 0.22, 0.45, and 0.9 keq/ha/yr for sensitive, moderately sensitive, and low sensitivity soils, respectively by AENV (1999). These target loads are established at approximately 90% of critical loads. Finally, monitoring loads for Alberta were set at 0.17, 0.35, and 0.7 keq H^+/ha/yr for sensitive, moderately sensitive, and low sensitivity soils, respectively by AENV (1999). When monitoring loads are exceeded, more field data are normally collected.

New loadings as fractions of critical, target, and monitoring loads for each grid cell were calculated using the same approach based on the RELAD modeled PAI for the years 1995, 2000, and 2010 (Figure 15) and the revised receptor sensitivity map for Alberta (Figure 22). These results are presented in Figures 23 to 25 for critical, target, and monitoring loads, respectively.

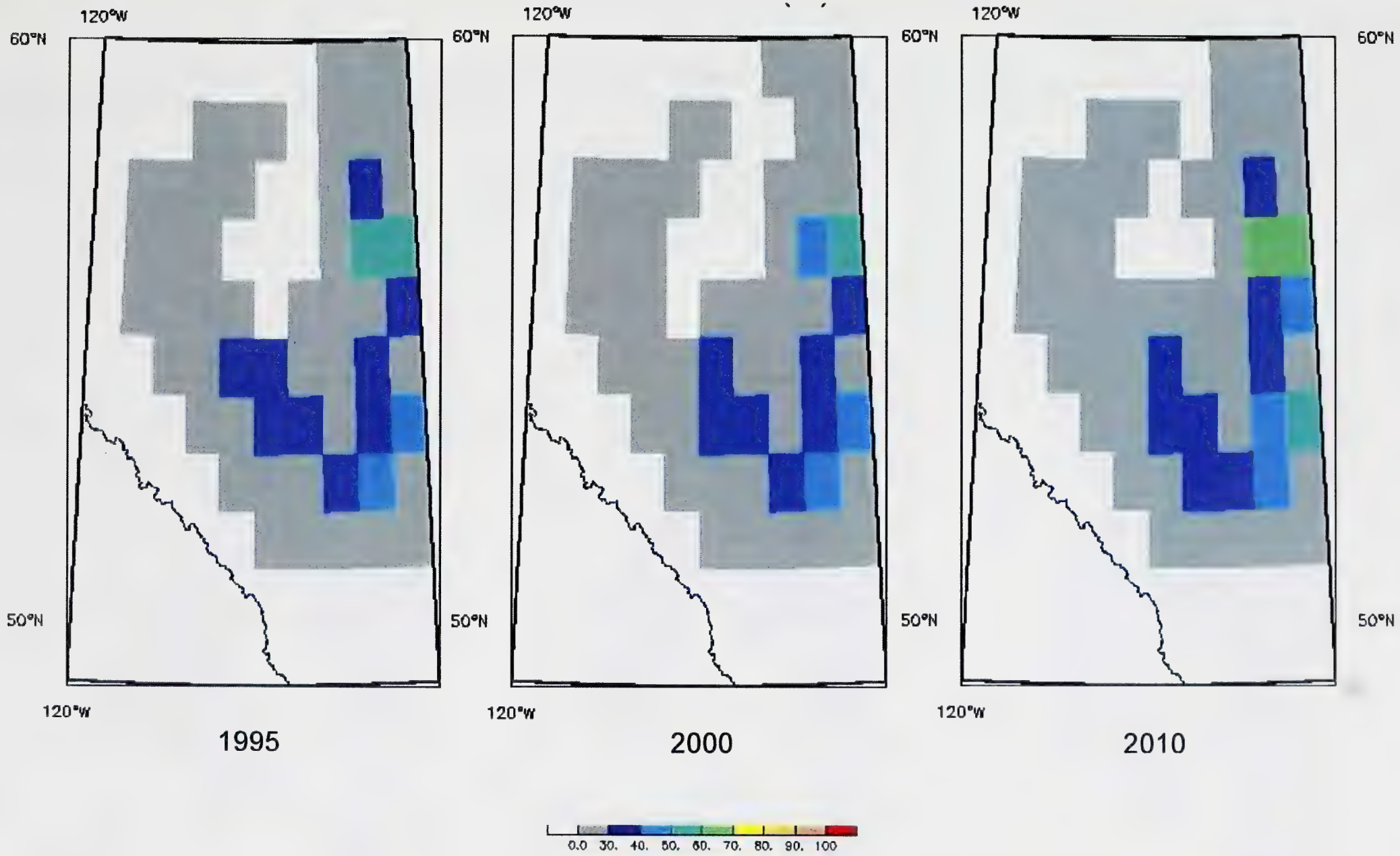

Figure 24 Revised acid deposition loading as a percent (%) of the critical load for the years 1995, 2000, and 2010 (projected) (values below zero indicate that base cation deposition exceeds acid deposition).

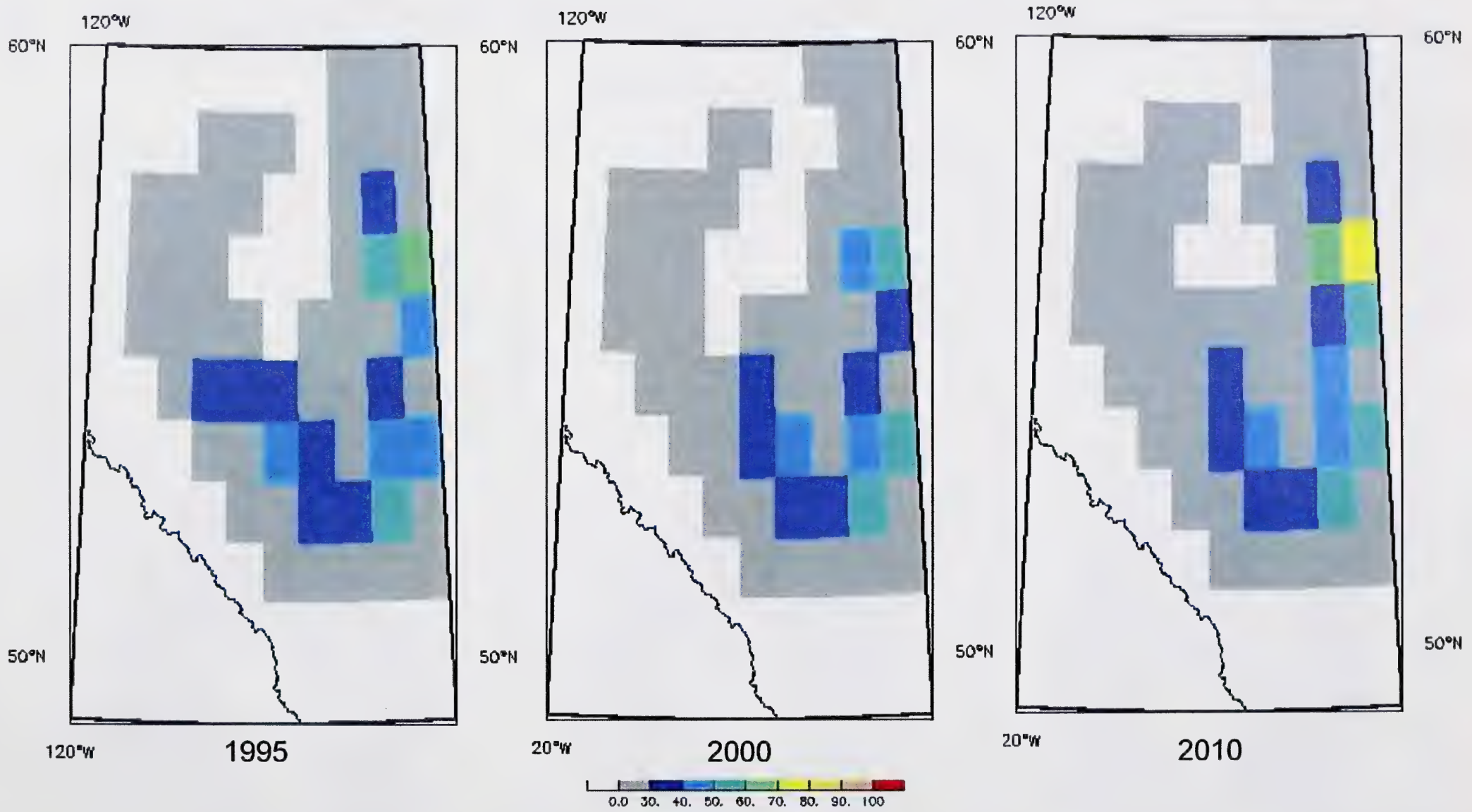

Figure 25 Revised acid deposition loading as a percent (%) of the target load for the years 1995, 2000, and 2010 (projected) (values below zero indicate that base cation deposition exceeds acid deposition).

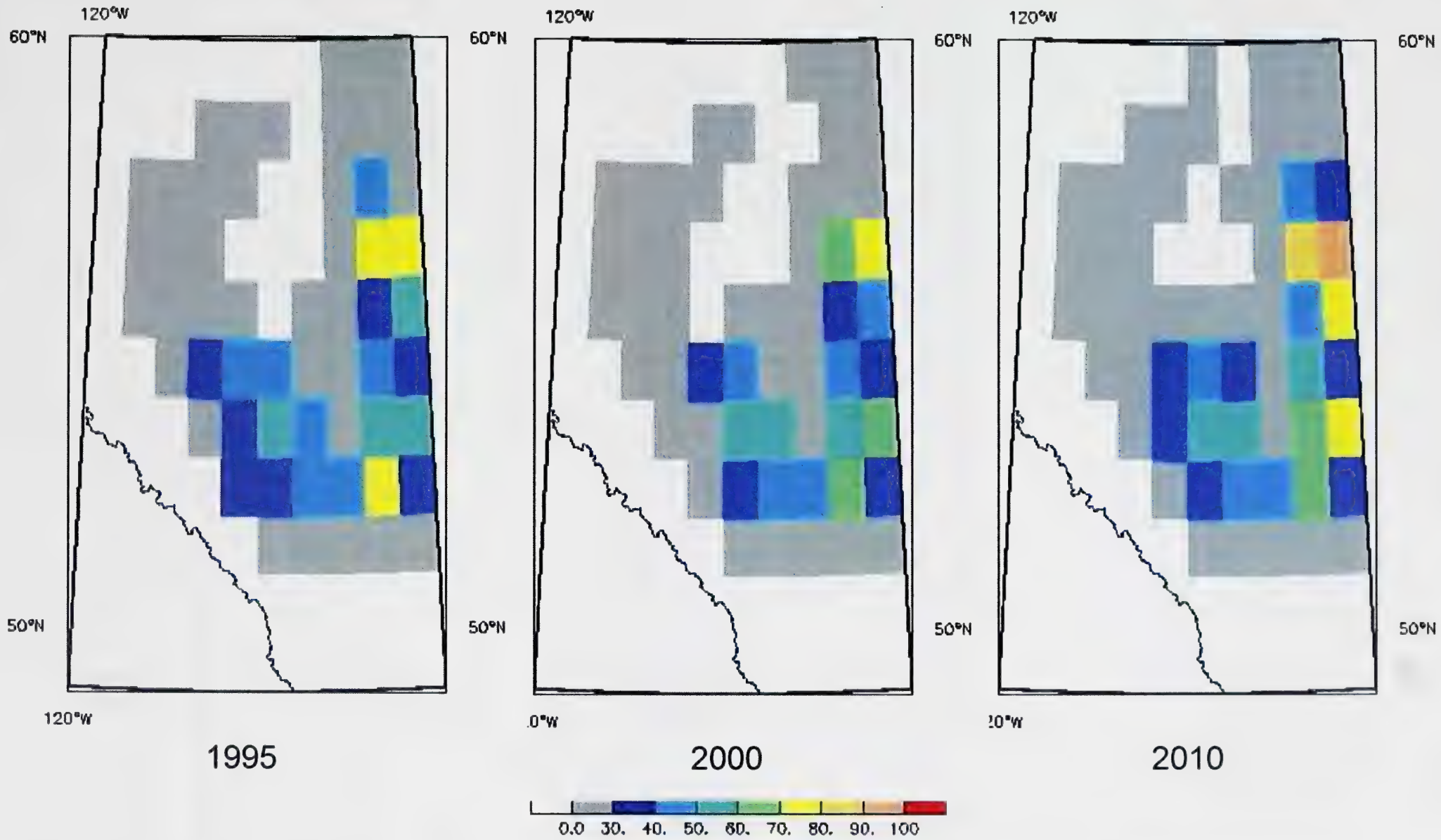

Figure 26 Revised acid deposition loading as a percent (%) of the monitoring load for the years 1995, 2000, and 2010 (projected) (values below zero indicate that base cation deposition exceeds acid deposition).

6.0 SCIENCE GAPS

Science gaps in acid deposition were identified and recommendations to fill these gaps were proposed in the first acid deposition assessment in Alberta (AENV, 1999). The status of these scientific gaps has been reviewed and is summarized below. New science gaps are also identified and future works are suggested to advance the understanding of acid deposition science in Alberta.

6.1 Status of Previous Identified Scientific Gaps

6.1.1 Aquatic Sensitivity

Organic acids may play a role in providing buffering to aquatic systems and in contributing to spring acid pulses. Recent evidence suggests that the balance between weak and strong organic acids may be such that organic acid anions are making systems more sensitive to deposition (i.e. they provide protons (H^+) rather than accept them at pH <5). The Cumulative Environmental Management Association (CEMA; www.cema.org) funded a project investigating the role of organic acids in buffering aquatic systems.

Spring acid flush has been investigated in the Fort McMurray region. This information has been put forward as being useful to the overall assessment in Alberta if snow pack chemistry can be related to a general mass-balance model and used the province. In general, In general, studies in northeastern Alberta indicate that acidic deposition was found an important factor with depressed pH and acid neutralizing capacity. Spring acid pulse not was found to be very important with depressions in acid neutralizing capacity; and very modest changes in pH were found to be a result of dilution and not due to stored deposition in the snow pack.

6.1.2 Mineral Soil Sensitivity

Mineral soil response to acid deposition has been studied by the Terrestrial Environmental Effects Monitoring (TEEM) of the Wood Buffalo Environmental Association and will be further studied through dynamic modeling by the NO_x-SO_2 Management Working Group of the Cumulative Environmental Management Association in the oil sands area.

6.1.3 Wetland (Organic Soil) Sensitivity

The current classification system is based on vegetative cover. A different classification system is needed to apply the sensitivity classification of Turchenek *et al.* (1998) for wetlands. A new system should be based on chemical/biotic criteria, involving peatland water and soil chemistry.

6.1.4 Role of Nitrogen Fertilization

A report was recently prepared for NO_x-SO_2 Management Working Group regarding nitrogen in boreal ecosystem and estimating the portion of nitrogen deposition that might be expected to contribute to acidification. Based on this report a recommendation was sent to Alberta Environment regarding the portion of nitrogen deposition that, in the oil sands region, should be considered acidifying. The issue of nitrogen fertilization in the oil sands area is currently being reviewed by the NO_x-SO_2 Management Working Group and the intent is to develop a regional management plan. The Terrestrial Environmental Effects Monitoring Group's acidification monitoring program includes some monitoring elements that provide data related to the possible fertilization effects of nitrogen.

6.1.5 Ecological Monitoring

A Long Term Soil Acidification Monitoring Program has been monitoring the effects of acid deposition on soils in Alberta since 1981. The Program was initiated by Alberta Environment at sites with soils that are sensitive to acid deposition. These sites are used to provide an early indication of soil acidification that may affect a broader area.

6.1.6 Survey Sampling of Receptor Sensitivity

Some soil sampling surveys have been done to support sensitivity mapping in the Athabasca oil sands region and in the Esther/Provost region. In addition, lake sampling surveys were conducted in the Lake Wabamun area around coal-fired power plants in Central Alberta and in the oil sands area.

6.2 New Scientific gaps and Suggested Future Work

6.2.1 Acid Deposition Field Measurements

Use of regional acid deposition models provides valuable information for understanding and managing acid deposition. However, direct measurements provide a means of obtaining more accurate information about actual amounts of depositing species. This assessment highlights the limited measurement data that exist on simultaneous wet and dry deposition of S and N species throughout Alberta (e.g., Table 4). More dedication needs to be given to having wet and dry deposition monitoring in regions of Alberta where acidifying emissions are anticipated to increase associated with development activity (e.g. oil sands).

6.2.2 Aquatic Sensitivity

The relevance of pH 6.0 as a cut off for aquatic organisms relevant to Alberta is being addressed through a number of aquatic and terrestrial projects by the NO_x-SO_2 Management Working Group, CEMA. A paleolimnology project is identifying historic fluctuations in pH and its relevance to one indicator of ecosystem integrity at the primary production level (diatoms). Terrestrial-related projects include assessments of N and S cycling in plant and wetland (bog) communities.

The role of groundwater inflow and water yield in general is being examined with new modeling tools (because sensitivity depends on the loading rates of base cations). The role of climate in causing variation in lake ANC and the natural variability in ANC that can be expected in Alberta lakes is being examined in the paleolimnology project to capture aquatic variability and peat cores to capture terrestrial variability.

Additional work needs to be done to better understand the relevance of pH 6.0 as the cut off for aquatic organisms applicable to Alberta; the role of groundwater inflow and water yield in general (because sensitivity depends on the loading rates of base cations); and the role of climate in causing variation in lake ANC and the natural variability in ANC that can be expected in Alberta lakes.

6.2.3 Criteria for Assessing Acidification in Soils

Additional work needs to be done in the development and use of criteria for assessing acidification in soils, particularly organic soils (e.g. base cation:aluminum (BC/Al) ratios, use of C:N ratios. etc.).

6.2.4 BC/Al Ratio Dose-response Relationships in Soils for Boreal Forest Species

Base cation:aluminum (BC/Al) ratios are used to estimate potential effects of soil acidification on plant growth. The Cumulative Environmental Management Association has established target BC/Al ratios that trigger acid emission management responses. Although these target ratios are based on scientific studies, only a few of Alberta's boreal forest species were included among the species studies. Most of these studies were carried out in hydroponics solutions rather than soil. Dose-response studies using Alberta boreal forest species are needed to validate the targets for the effects of acid emissions on forest soils and vegetation.

6.2.5 Role of Nitrogen in Soil Acidification

Nitrogen cycles through soil and vegetation in a multi-step process. Deposited nitrogen is generally considered to contribute to acidification only if nitrate leaches from the plant rooting zone carrying with it base cations, although some scientists believe that cycling of deposited nitrogen in the ecosystem is inherently acidifying. The framework treats all deposited nitrogen as acidifying. While this may be a valid assumption under certain circumstances, more generally a portion of deposited nitrogen is semi-permanently sequestered in the ecosystem; for the most

part it is in the form of soil organic matter recalcitrant to decomposition, and does not contribute to acidification. Consequently, the current assessment of PAI will generally overestimate actual acidifying input due to nitrogen. This issue is becoming increasing significant as nitrogen is becoming an increasing larger proportion of acidifying deposition in Alberta and worldwide, due to reduced sulphur emissions and, in areas with growing populations and/or industrial development, increasing nitrogen emissions. Nitrogen cycling and fate in Alberta ecosystems is not well understood.

6.2.6 Nitrogen Cycling

Additional work needs to be done in understanding nitrogen deficits across the range of provincial soils and the potential for enhanced nitrate leaching in soil systems.

6.2.7 Need for Updating of the Alberta Soil Sensitivity Ratings

Sensitivity of Alberta soils was last evaluated and classified by Holowaychuk and Fessenden (1987) for the Acid Deposition Research Program (ADRP) in 1987. Since that time, significant advances have been made in the understanding of soil acidification processes. Models used to estimate the response of soils to acid inputs have improved, allowing better estimates of which soils are likely to be sensitive to acid deposition. When this knowledge is coupled with the distribution of soil series within a management zone, one can better manage acid emissions within that zone.

Work is underway by Alberta Environment to update soil sensitivity ratings for those grid cells that have Long-Term Soil Acidification Monitoring plots. Updating soil sensitivity ratings for the Provost-Esther grid cells and the oil sands area have been completed. The Edmonton grid cell is currently being revised. Priority grid cells for future review include the area northeast of Edmonton (downwind of Ft. Saskatchewan, Bruderheim, and Redwater) and the area around Rocky Mountain House.

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APPENDICES

APPENDIX I ALBERTA ENVIRONMENT ACID DEPOSITION ASSESSMENT GROUP (ADAG) MEMBERSHIP

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Markus Kellerhals	Environment Canada, Edmonton, AB
Martha Kostuch	Prairie Acid Rain Coalition
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Ron Pauls	Syncrude Canada Ltd., Fort McMurray, AB
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Bob Myrick	Alberta Environment, Edmonton, AB
Crystal Parrell	Alberta Environment, Edmonton, AB
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Martina Krieger	Alberta Environment, Edmonton, AB
Corinna Watt	Environment Canada, Edmonton, AB

APPENDIX II RELAD RUNS FOR SELECTION OF REPRESENTATIVE METEOROLOGICAL YEAR BETWEEN 1971 AND 2000

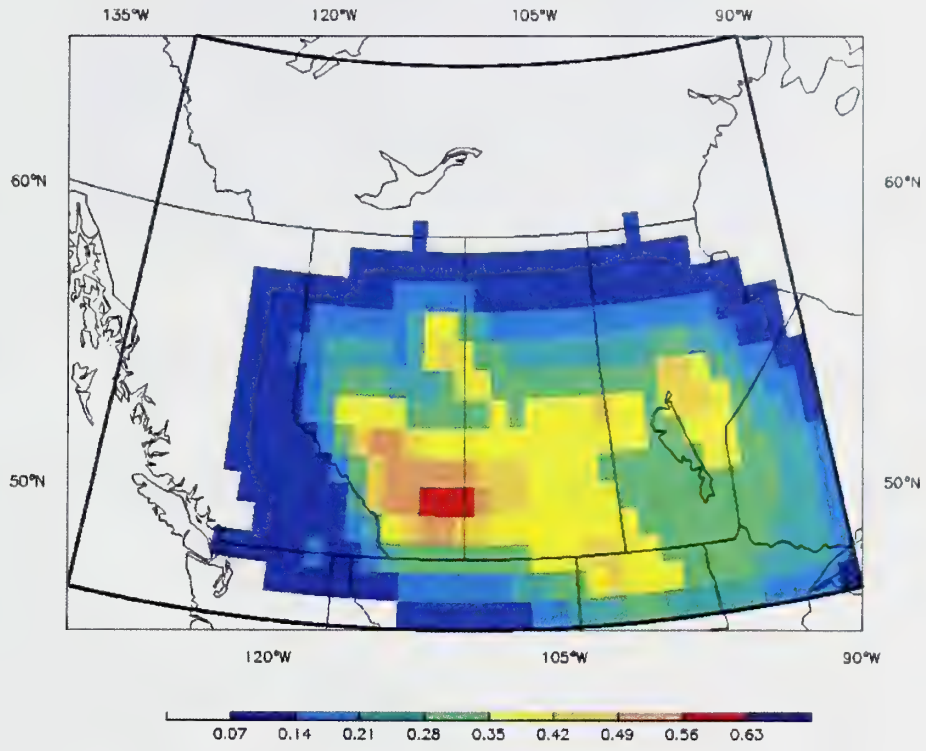

Figure II.1 RELAD 30-year mean NH_4SO_4 concentration ($\mu g\ m^{-3}$).

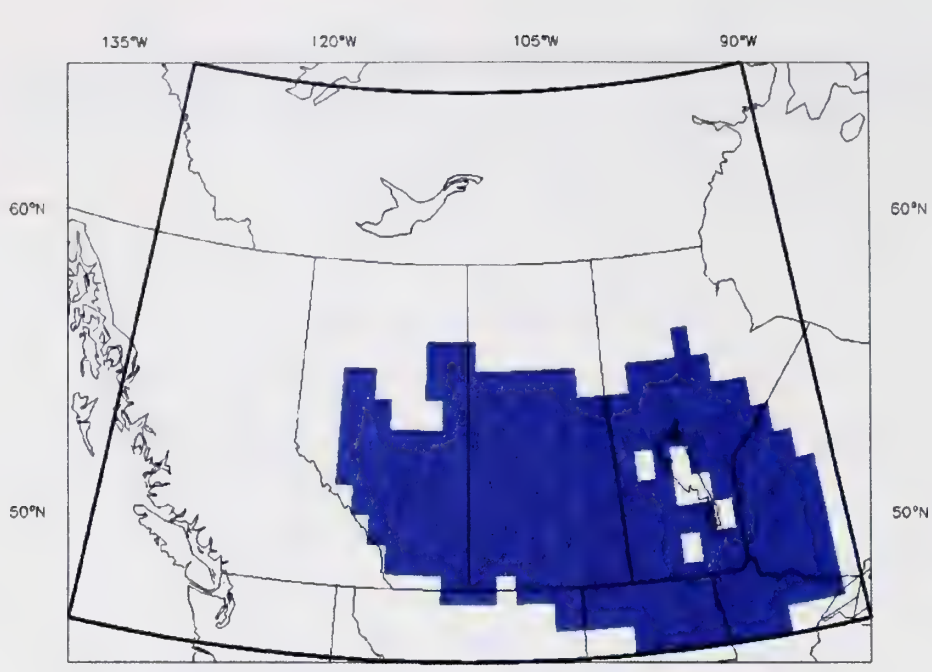

Figure II.2 RELAD 30-year mean NH_4SO_4 dry deposition (keq H^+/ha/yr).

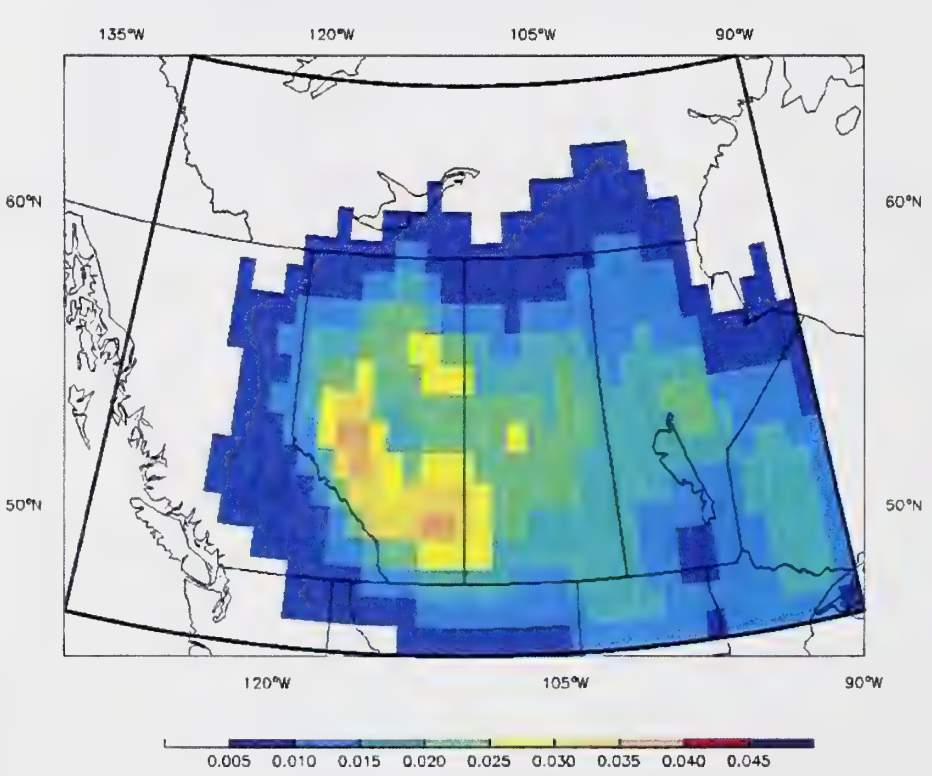

Figure II.3 RELAD 30-year mean NH_4SO_4 wet deposition (keq H^+/ha/yr).

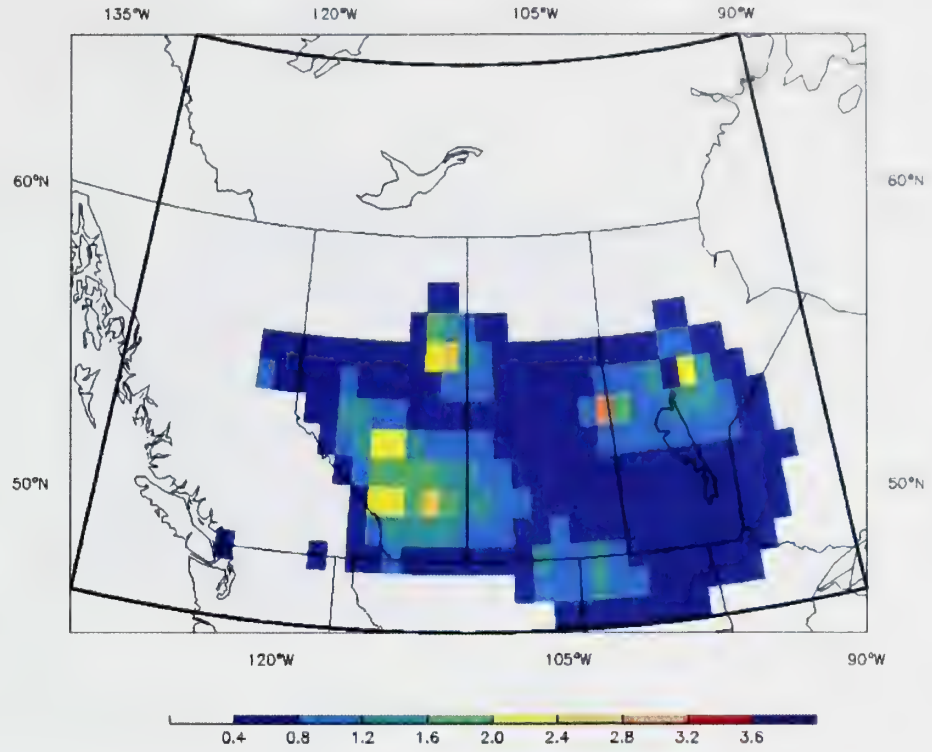

Figure II.4 RELAD 30-year mean sulphur concentration (μg m^{-3}).

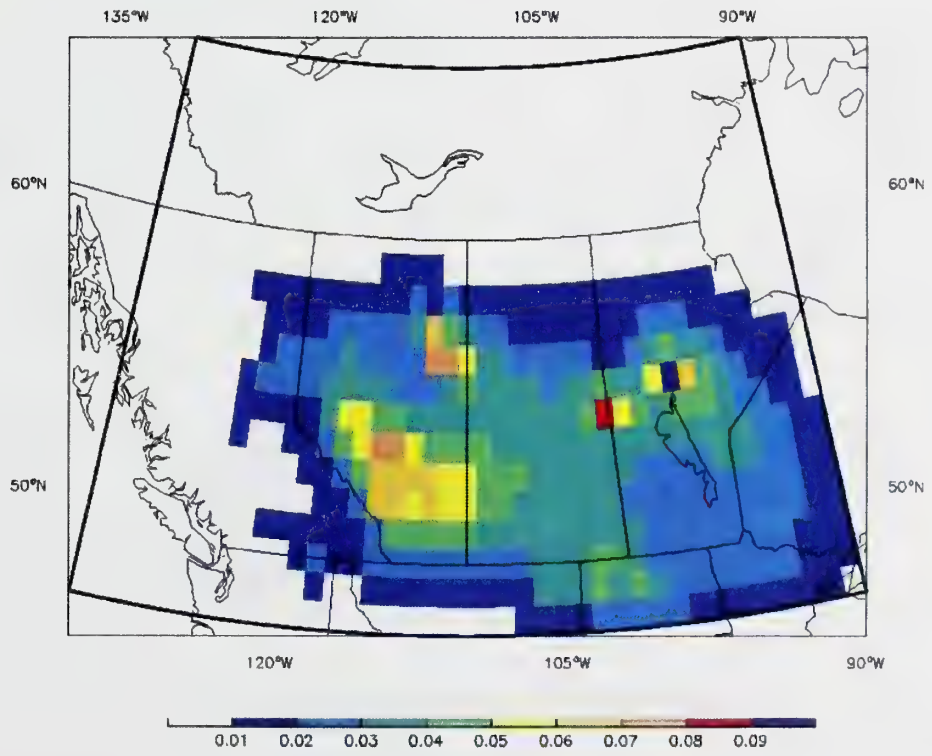

Figure II.5 RELAD 30-year mean sulphur dry deposition (keq H^+/ha/yr).

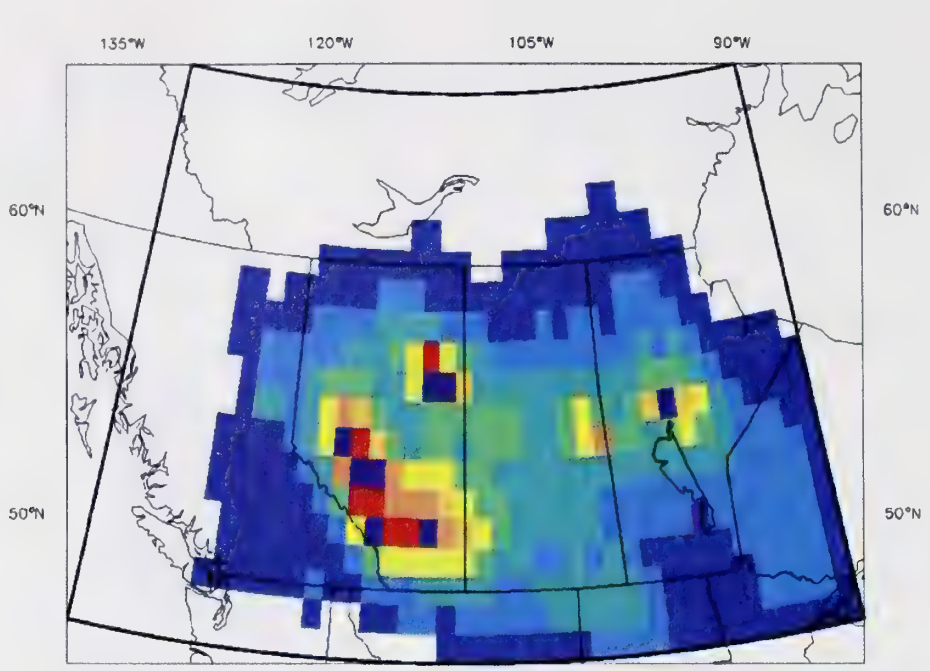

Figure II.6 RELAD 30-year mean sulphur wet deposition (keq H^+/ha/yr).

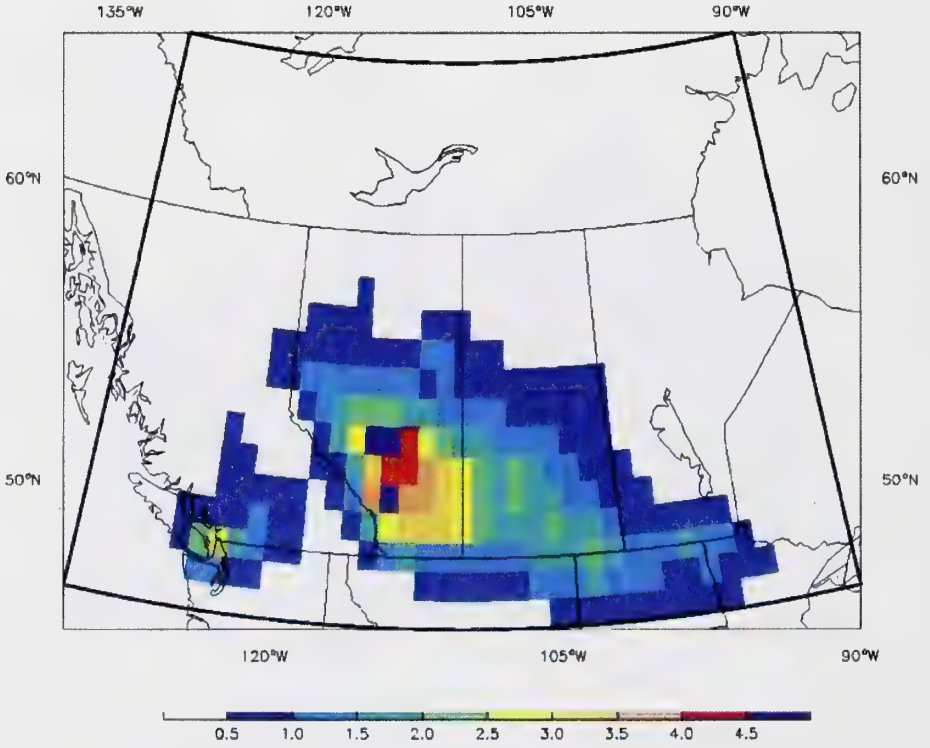

Figure II.7 RELAD 30-year mean NO_x concentration as NO_2 ($\mu g\ m^{-3}$).

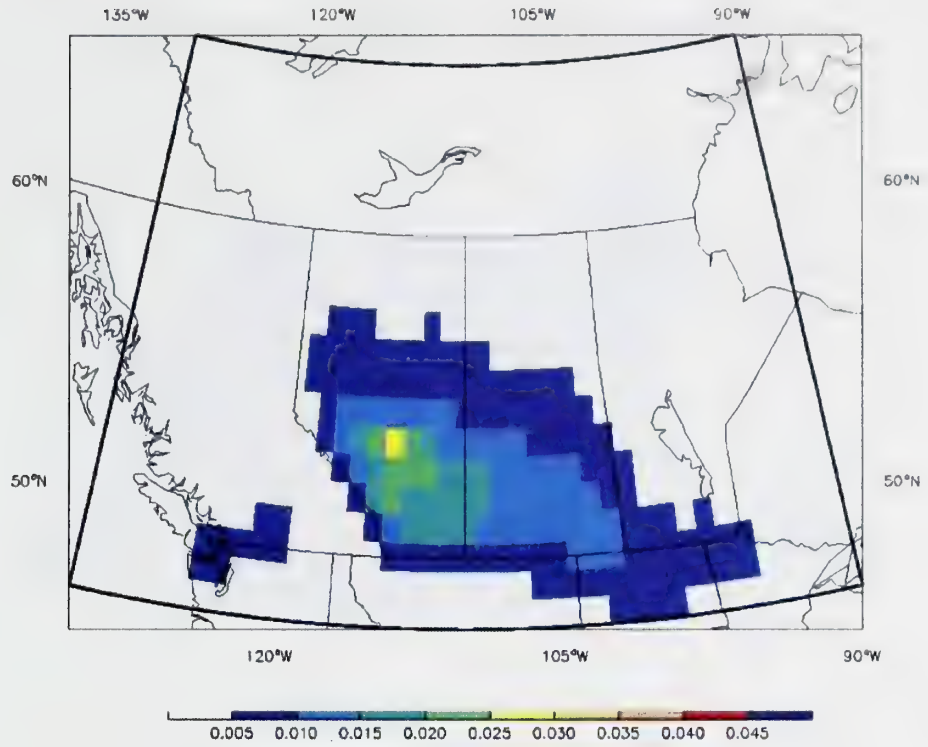

Figure II.8 RELAD 30-year mean NO_x dry deposition (keq H^+/ha/yr).

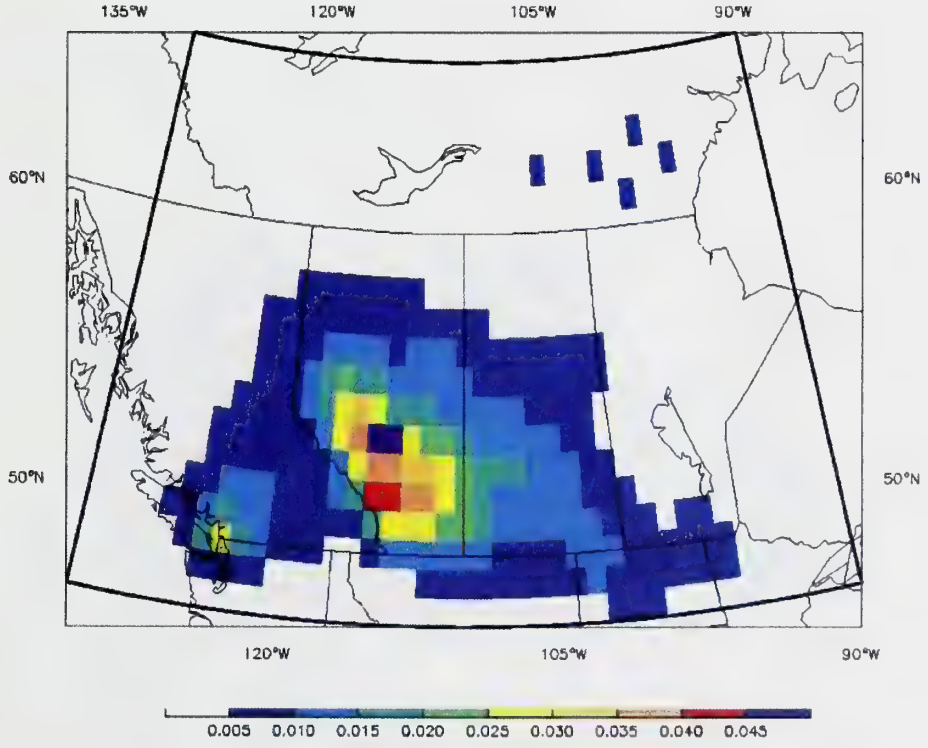

Figure II.9 RELAD 30-year mean NO_x wet deposition (keq H^+/ha/yr).

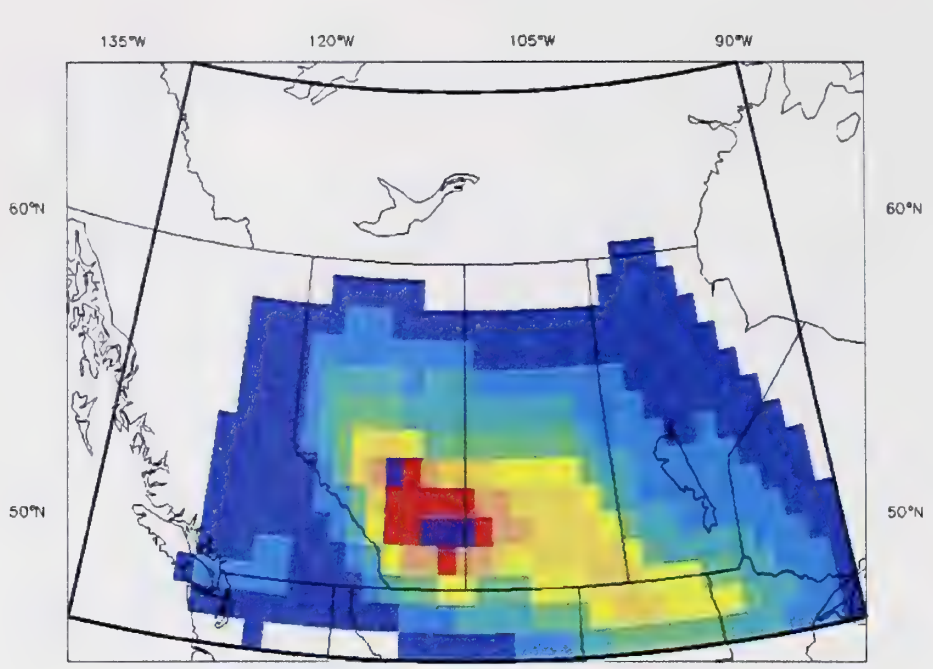

Figure II.10 RELAD 30-year mean NO_3 concentration (μg m^{-3}).

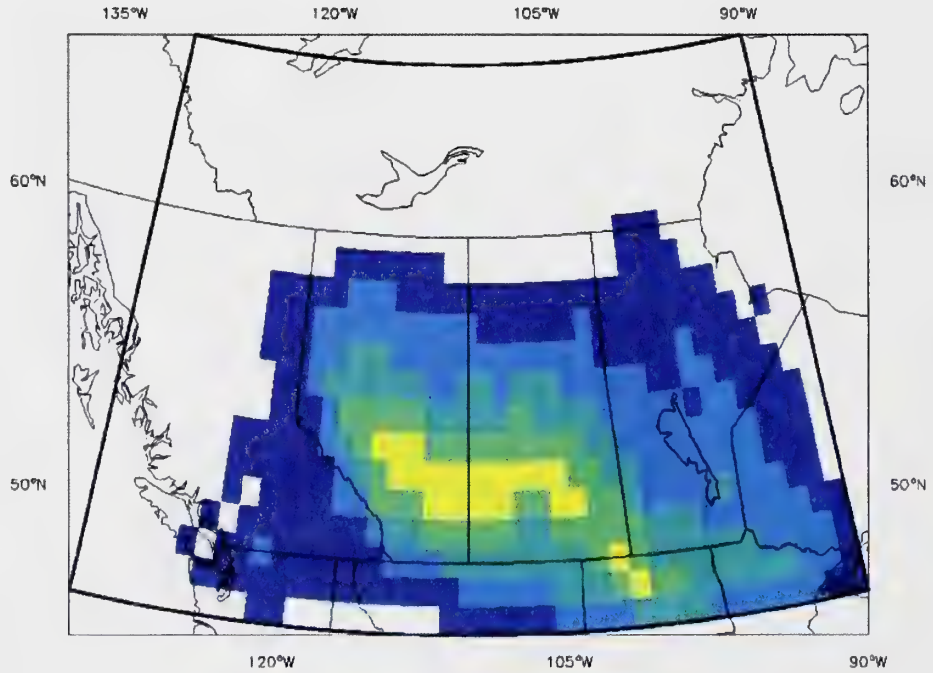

Figure II.11 RELAD 30-year mean NO_3 dry deposition (keq H^+/ha/yr).

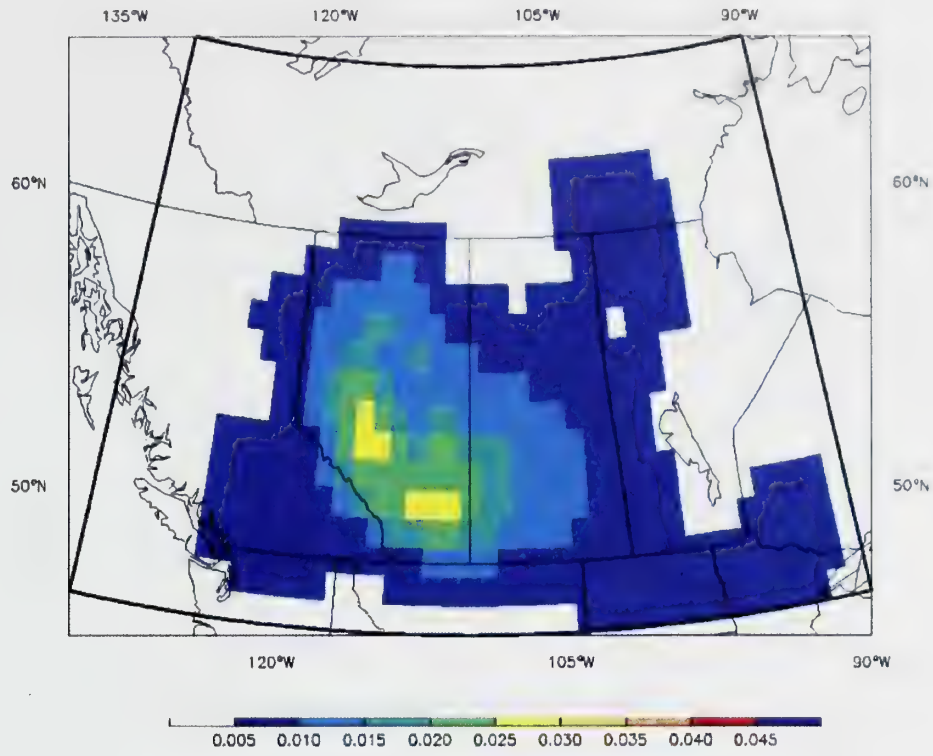

Figure II.12 RELAD 30-year mean NO_3 wet deposition (keq H^+/ha/yr).

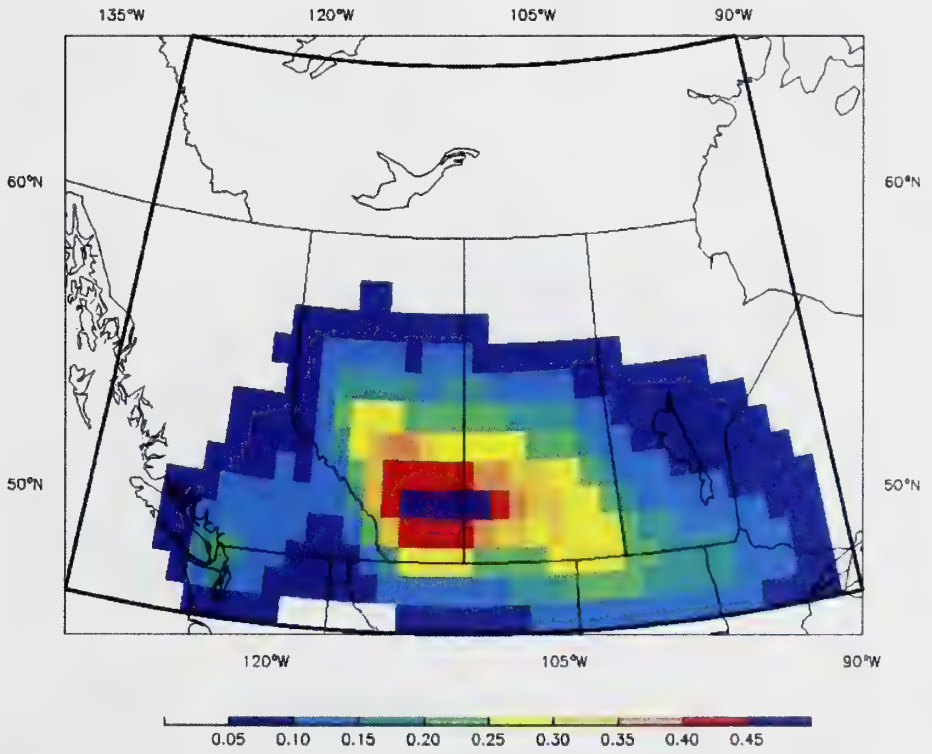

Figure II.13 RELAD 30-year mean NH_4NO_3 concentration ($\mu g\ m^{-3}$).

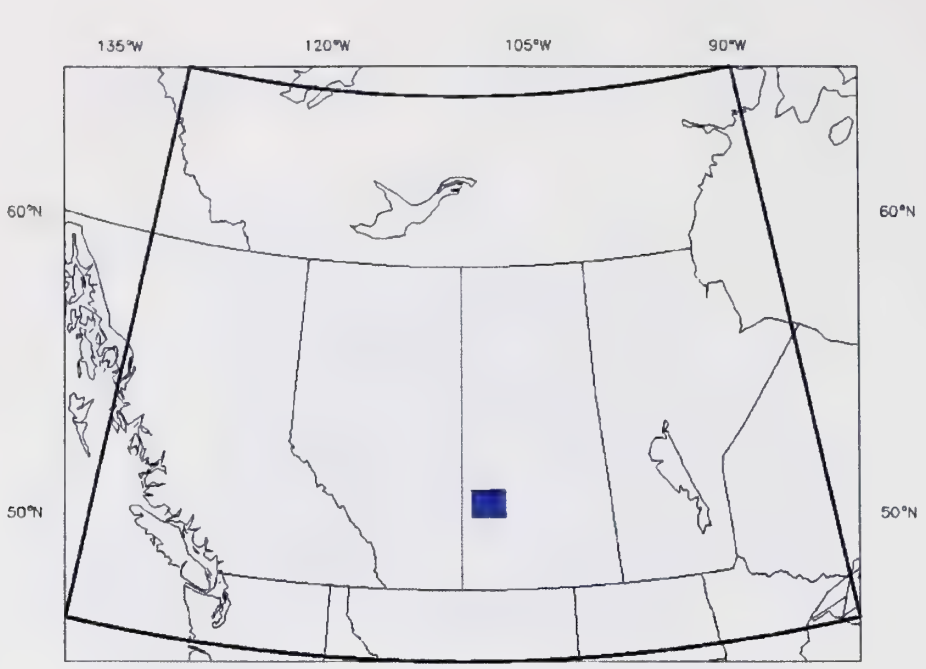

Figure II.14 RELAD 30-year mean NH_4NO_3 dry deposition (keq H^+/ha/yr).

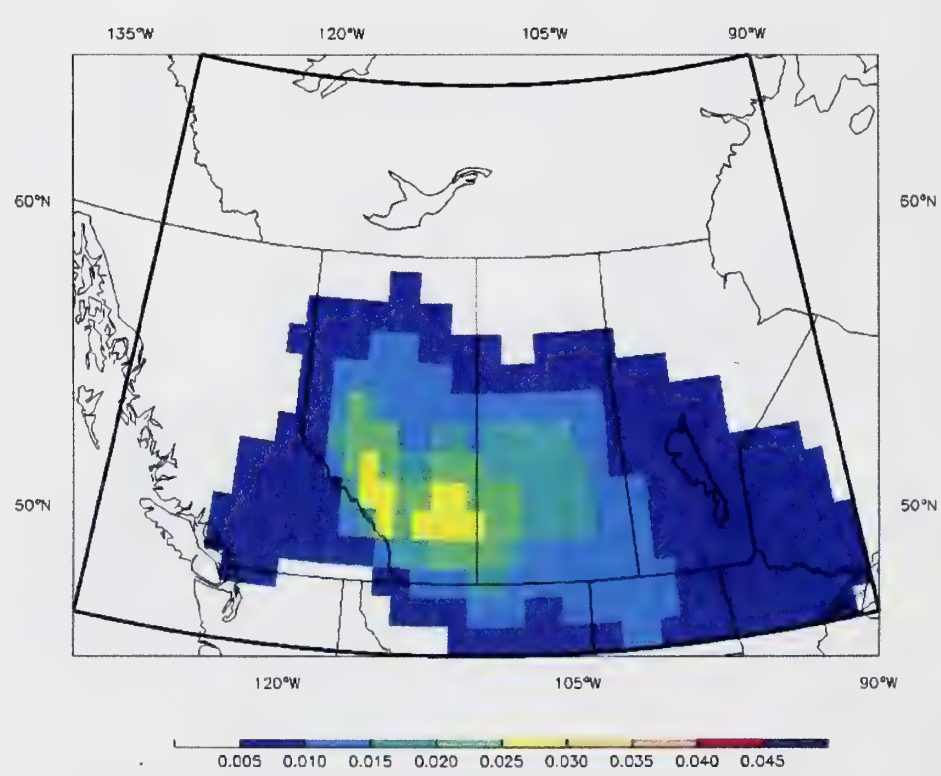

Figure II.15 RELAD 30-year mean NH_4NO_3 wet deposition (keq H^+/ha/yr).

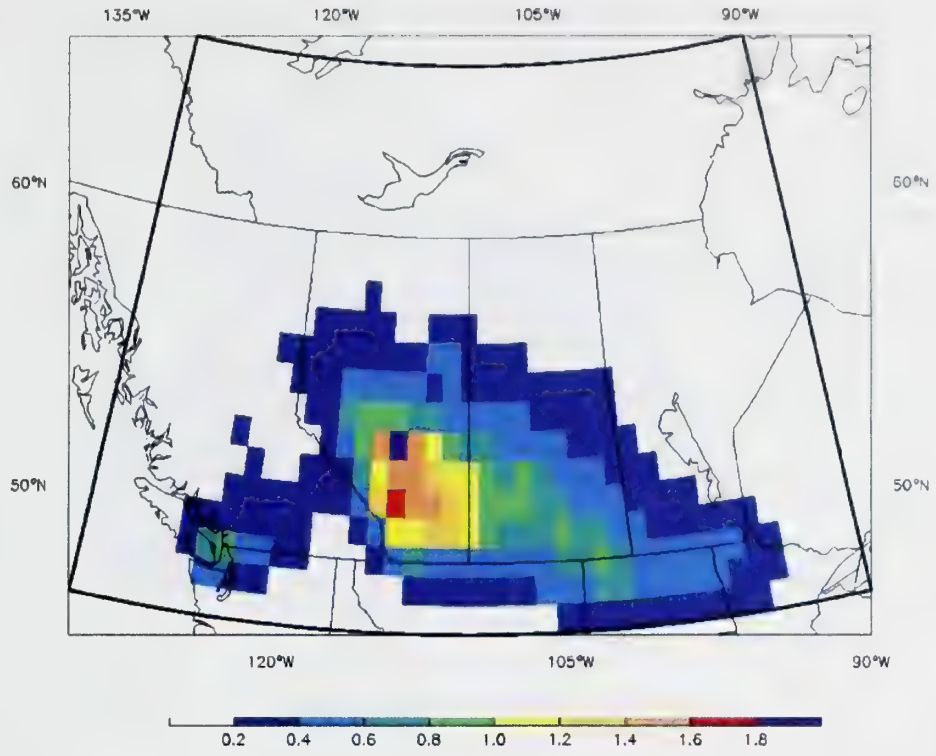

Figure II.16 RELAD 30-year mean nitrogen concentration (μg m^{-3}).

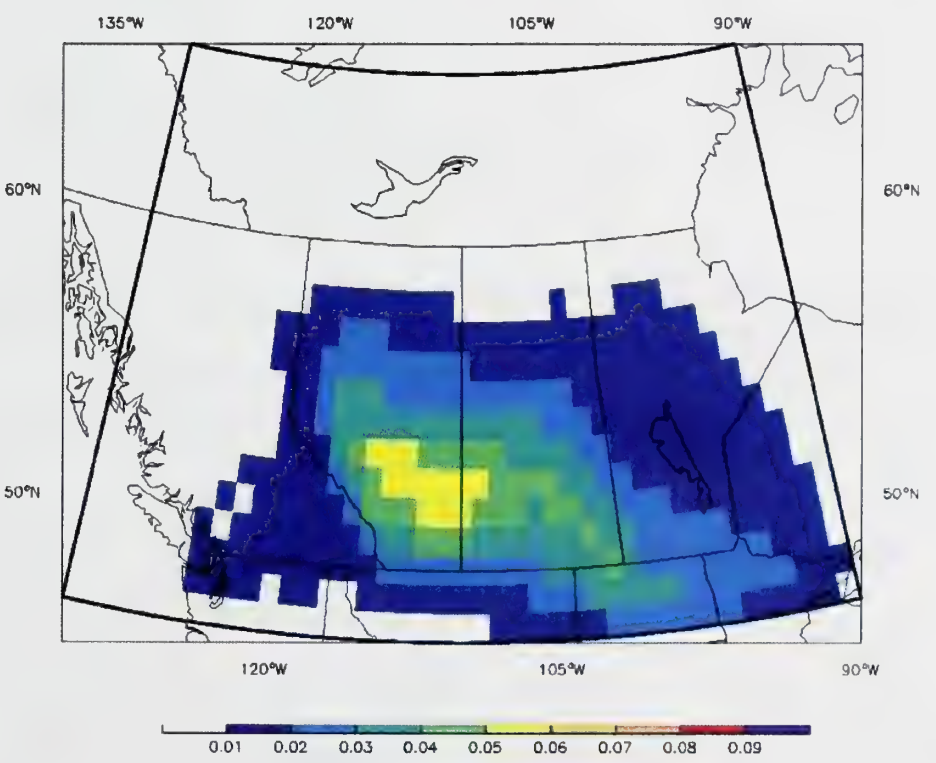

Figure II.17 RELAD 30-year mean nitrogen dry deposition (keq H^+/ha/yr).

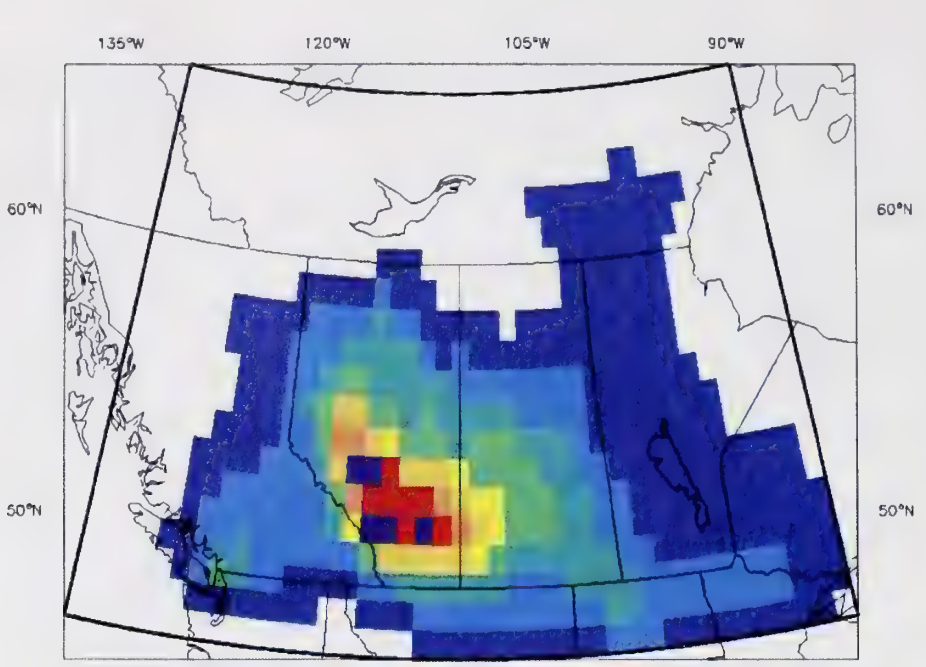

Figure II.18 RELAD 30-year mean nitrogen wet deposition (keq H^+/ha/yr).

APPENDIX III STATISTICAL MEASURES USED TO EXAMINE RELAD RESULTS FOR CHEMICAL SPECIES' CONCENTRATIONS AND DEPOSITION RATES

Statistical measures that were used to examine and compare RELAD results for 30-year means of chemical species' concentrations and deposition rates versus individual-year (1971 to 2000) means of chemical species' concentrations and deposition rates included:

BIAS =	mean differences between values of the individual years and the 30-year mean at each cell
VAR =	variance of differences between values of the individual years and the 30-year mean at each cell
RMSE =	root mean square error of the differences between values of the individual years and the 30-year mean at each cell
RMSES =	systematic part of the RMSE
REMSU =	unsystematic part of the RMSE
MAE =	mean absolute error of the differences between values of the individual years and the 30-year mean at each cell
INTERCEPT =	intercept of the regression line for values of the individual years and the 30-year mean at each cell
SLOPE =	slope of the regression line for values of the individual years and the 30-year mean at each cell
CORR =	cross-correlation coefficient between values of the individual years and the 30-year mean at each cell
INDEX 1 =	Wilmott's modified index of agreement
INDEX 2 =	Wilmott's index of agreement

Table III.1 presents statistical measures for individual years when compared with the 30-year mean SO_2 concentration. Scores were applied to each result (lowest score = 1 for largest deviation between an individual year result and 30-mean result, to highest score = 30 for smallest deviation between an individual year result and 30-mean result for each statistical measure in each year) in Table III.2. The colored cells indicate the meteorological year with the highest score (30). The highest score (30) indicated that the data for that year was closest to the 30_year average Although not shown, scoring tables similar to Table III.2 were generated for each of the remaining parameters used in RELAD:

- SO_2 dry deposition rates, SO_2 wet deposition rates
- $(NH_4)_2SO_4$ concentrations, $(NH_4)_2SO_4$ dry deposition rates, $(NH_4)_2SO_4$ wet deposition rates
- NO_x concentrations, NO_x dry deposition rates, NO_x wet deposition rates
- HNO_3 concentrations, HNO_3 dry deposition rates, HNO_3 wet deposition rates
- NH_4NO_3 concentrations, NH_4NO_3 dry deposition rates, NH_4NO_3 wet deposition rates

Next, an average score for the nine statistical measures was estimated for each parameter and summarized for each meteorological year (refer to Table III.3 for sulphur parameters and Table III.4 for nitrogen parameters used by RELAD). Again, colored cells indicate the meteorological year with the highest average score for all statistical measures. Finally, summary scores were computed for: total S concentrations, total S dry deposition rates, and total S wet deposition rates; and total N concentrations, total N dry deposition rates, and total N wet deposition rates (Table III.5). The colored cells indicate the meteorological year with the highest average score for each parameter.

These summary scores (Table III.5) were used to identify the meteorological year – 1980 in this case – that had the greatest number of high scores for sulphur and nitrogen parameters examined. As a result, the 1980 meteorological year was selected as the optimum meteorological year for subsequent RELAD runs using 1995, 2000, and projected 2010 emissions data.

As a final check, RELAD results for the thirty-year mean (1971 to 2000) were visually compared to results for selected individual meteorological years (1980, 1990, and 1995) in plots for the following model outputs (Figures III.1 to III.9, respectively):

- total sulphur concentration
- total nitrogen concentration
- total sulphur deposition
- total nitrogen deposition
- total nitrogen and sulphur deposition

Although not exact, these plots visually show that RELAD results for the 1980 meteorological year are more comparable to the thirty-year mean (1971 to 2000) results relative to the 1990 and 1995 meteorological year results. This is observed by a smaller amount of differences in "thirty-year mean (1971 to 2000) results" minus the "individual year (1980, 1990, and 1995) results" for the above model outputs.

Table III.1 Statistical measures for individual years when compared with 30-year mean SO_2 concentration.

	BIAS	VAR	RMSE	RMSES	RMSEU	MAE	INTERCEPT	SLOPE	CORR	INDEX1	INDEX2
1971	-0.010	0.010	0.099	0.042	0.958	0.076	0.010	0.983	0.996	0.950	0.998
1972	0.022	0.017	0.132	0.471	0.529	0.088	-0.080	1.084	0.996	0.944	0.996
1973	0.048	0.026	0.169	0.101	0.899	0.119	0.020	1.023	0.989	0.921	0.994
1974	0.030	0.021	0.149	0.076	0.924	0.102	-0.004	1.027	0.991	0.934	0.995
1975	0.035	0.011	0.110	0.281	0.719	0.078	-0.020	1.045	0.996	0.949	0.997
1976	-0.031	0.006	0.086	0.143	0.857	0.062	-0.041	1.008	0.997	0.959	0.998
1977	-0.009	0.012	0.109	0.006	0.994	0.073	-0.006	0.998	0.995	0.952	0.997
1978	-0.001	0.021	0.144	0.005	0.995	0.106	0.011	0.990	0.991	0.930	0.995
1979	0.069	0.017	0.147	0.590	0.410	0.094	-0.036	1.085	0.997	0.940	0.995
1980	0.016	0.009	0.098	0.039	0.961	0.069	0.004	1.010	0.996	0.955	0.998
1981	0.020	0.005	0.075	0.077	0.923	0.054	0.028	0.993	0.998	0.964	0.999
1982	-0.002	0.018	0.135	0.017	0.983	0.101	0.018	0.983	0.992	0.933	0.996
1983	0.062	0.033	0.191	0.145	0.855	0.132	0.017	1.037	0.987	0.914	0.992
1984	-0.006	0.007	0.086	0.066	0.934	0.061	0.019	0.980	0.997	0.960	0.998
1985	-0.072	0.035	0.200	0.400	0.600	0.125	0.049	0.901	0.987	0.916	0.990
1986	-0.017	0.012	0.111	0.025	0.976	0.077	-0.016	0.999	0.995	0.950	0.997
1987	0.033	0.021	0.148	0.063	0.937	0.109	0.053	0.984	0.990	0.928	0.995
1988	-0.028	0.014	0.120	0.139	0.862	0.080	0.012	0.967	0.994	0.947	0.997
1989	-0.073	0.024	0.172	0.190	0.810	0.128	-0.051	0.982	0.989	0.918	0.993
1990	-0.044	0.033	0.185	0.126	0.874	0.125	0.013	0.953	0.985	0.917	0.992
1991	-0.071	0.030	0.186	0.354	0.646	0.113	0.029	0.918	0.988	0.924	0.991
1992	0.010	0.004	0.063	0.092	0.908	0.047	-0.010	1.016	0.998	0.969	0.999
1993	-0.059	0.012	0.126	0.293	0.707	0.091	-0.021	0.968	0.995	0.940	0.996
1994	-0.004	0.012	0.107	0.002	0.998	0.080	-0.006	1.002	0.995	0.947	0.997
1995	0.013	0.023	0.150	0.156	0.844	0.094	-0.054	1.055	0.992	0.939	0.995
1996	-0.006	0.024	0.156	0.002	0.998	0.107	-0.006	1.000	0.989	0.930	0.994
1997	-0.018	0.011	0.108	0.147	0.853	0.076	0.026	0.964	0.995	0.949	0.997
1998	0.100	0.108	0.343	0.096	0.904	0.243	0.059	1.034	0.957	0.839	0.975
1999	-0.022	0.020	0.144	0.148	0.852	0.101	0.037	0.951	0.991	0.932	0.995
2000	0.017	0.026	0.161	0.153	0.847	0.112	-0.054	1.058	0.991	0.928	0.994

Table III.2 Scores of measures for individual years when compared with 30-year mean SO_2 concentration.

	BIAS	VAR	RMSE	MAE	INTERCEPT	SLOPE	CORR	INDEX1	INDEX2
1971	23	25	25	24	24	19	23	25	26
1972	16	16	17	18	1	3	26	18	18
1973	8	6	7	6	15	16	7	6	7
1974	13	11	11	12	30	15	13	14	12
1975	10	24	21	21	16	9	25	22	24
1976	12	28	28	27	8	25	29	28	29
1977	25	21	22	25	28	27	20	26	23
1978	30	13	15	11	23	24	10	11	14
1979	5	17	13	15	10	2	27	17	15
1980	21	26	26	26	29	23	24	27	27
1981	17	29	29	29	12	26	19	19	19
1982	29	15	16	13	18	20	14	13	16
1983	6	2	2	2	19	10	4	2	5
1984	27	27	27	28	17	17	28	29	28
1985	3	4	4	5	7	1	3	3	2
1986	19	20	20	22	20	29	17	24	21
1987	11	12	12	8	5	22	9	8	10
1988	14	18	19	19	22	13	16	20	20
1989	2	9	6	3	6	18	6	5	6
1990	9	3	5	4	21	7	2	4	4
1991	4	5	3	7	11	4	5	7	3
1992	24	30	30	30	25	21	30	30	30
1993	7	19	18	17	14	14	18	16	17
1994	28	22	24	20	26	28	21	21	25
1995	22	10	10	16	3	5	15	15	13
1996	26	8	9	10	27	30	8	10	8
1997	18	23	23	23	13	11	22	23	22
1998	1	1	1	1	2	12	1	1	1
1999	15	14	14	14	9	6	11	12	11
2000	20	7	8	9	4	8	12	9	9

Table III.3 Summary of scores of measures for individual years when compared with 30-year mean S species.

	SO2C	SO2DD	SO2WD	NH4SO4C	NH4SO4DD	NH4SO4WD
1971	23.8	14.6	3.8	18.4	10.9	4.8
1972	14.8	11.1	8.1	8.6	8.2	14.9
1973	8.7	4.4	3.8	12.0	11.1	4.2
1974	14.6	21.3	22.1	16.9	22.0	25.1
1975	19.1	21.0	14.9	15.1	13.2	17.7
1976	23.8	24.2	16.3	24.7	27.0	9.1
1977	24.1	23.1	19.4	24.3	22.4	13.4
1978	16.8	16.2	15.8	16.6	15.4	21.4
1979	13.4	9.2	15.8	5.0	3.3	26.8
1980	25.4	28.8	24.3	25.9	27.0	26.6
1981	22.1	22.1	22.3	23.7	24.9	20.4
1982	17.1	18.2	23.6	11.6	10.2	20.6
1983	5.8	3.9	14.6	6.9	7.0	6.4
1984	25.3	29.0	21.2	27.2	25.0	11.1
1985	3.6	6.2	5.3	9.6	14.2	11.0
1986	21.3	23.2	27.2	18.0	15.4	22.2
1987	10.8	15.3	24.9	11.7	16.3	22.8
1988	17.9	17.9	14.4	24.2	26.4	8.3
1989	6.8	6.9	8.0	8.7	11.2	9.7
1990	6.6	5.4	20.2	8.4	9.8	10.2
1991	5.4	9.8	22.4	10.9	13.1	15.4
1992	27.8	26.9	24.3	28.0	22.7	24.7
1993	15.6	14.4	9.3	15.4	13.3	18.6
1994	23.9	18.7	15.6	17.8	15.1	16.7
1995	12.1	13.4	5.2	18.0	17.6	7.6
1996	15.1	10.8	14.6	10.4	10.6	15.1
1997	19.8	16.9	16.3	18.6	18.8	18.2
1998	2.3	2.8	3.3	2.0	2.6	3.0
1999	11.8	10.9	17.6	7.0	7.8	27.2
2000	9.6	18.2	10.2	19.6	22.3	11.8

Table III.4 Summary of scores of measures for individual years when compared with 30-year mean N species.

	NOXC	NOXDD	NOXWD	NO3C	NO3DD	NO3WD	NH4NO3C	NH4NO3DD	NH4NO3WD
1971	23.8	25.2	1.7	20.1	14.9	8.3	14.4	12.9	7.0
1972	13.9	10.3	6.3	8.3	5.8	15.7	27.8	21.8	23.0
1973	15.8	8.0	7.6	22.3	15.3	3.4	13.4	5.0	5.8
1974	15.0	18.2	18.9	13.6	19.7	15.8	18.8	21.1	24.0
1975	18.8	16.6	14.2	14.3	11.1	16.9	26.4	24.9	18.0
1976	23.9	25.2	16.1	23.2	22.0	24.2	25.4	26.6	3.8
1977	18.1	21.7	25.1	11.9	13.1	6.8	8.4	11.4	11.9
1978	10.4	11.8	13.6	17.2	19.7	15.1	10.6	9.4	25.2
1979	17.4	16.2	15.4	6.0	4.7	24.2	12.0	14.7	22.0
1980	25.3	27.3	21.8	21.0	27.3	27.8	23.7	24.7	27.8
1981	23.8	24.3	20.7	26.2	27.6	26.1	15.9	14.7	19.1
1982	14.2	13.1	20.8	8.0	9.8	23.6	6.7	8.9	7.6
1983	6.7	4.4	14.6	8.6	7.4	7.2	17.3	15.3	16.7
1984	24.7	26.4	21.4	23.0	22.1	19.0	14.8	12.2	9.1
1985	3.0	4.3	7.3	7.9	9.1	10.8	12.0	18.6	13.4
1986	27.6	24.8	26.2	19.8	20.1	19.2	10.9	7.8	13.4
1987	11.0	13.4	27.2	11.4	19.7	21.9	22.0	24.7	22.8
1988	20.2	21.6	16.9	25.7	20.0	11.2	22.9	26.7	7.6
1989	9.3	9.0	7.2	14.2	16.1	11.0	14.9	15.2	15.6
1990	8.2	8.0	25.1	15.3	12.0	23.2	14.0	13.6	10.8
1991	6.0	7.3	22.9	19.3	21.8	19.0	5.3	5.4	12.2
1992	25.1	25.2	23.3	21.2	24.9	21.8	6.0	3.2	17.6
1993	17.7	14.4	10.1	9.1	6.3	11.0	7.1	11.1	12.0
1994	19.7	18.4	15.0	22.1	14.2	12.4	13.7	12.2	27.9
1995	11.8	17.6	7.0	23.8	26.2	6.2	15.7	16.1	14.2
1996	12.0	10.3	14.7	13.3	13.6	19.2	9.2	8.2	16.6
1997	17.4	16.0	17.8	10.3	10.1	23.9	15.0	15.3	25.0
1998	3.6	3.7	3.1	4.2	4.1	1.6	25.1	19.8	12.8
1999	12.6	12.1	15.8	6.6	6.1	9.2	13.4	20.0	4.1
2000	8.1	9.9	7.2	16.9	20.2	9.2	22.1	23.6	18.2

Table III.5 Summary of scores of measures for individual years when compared with 30-year mean for total S and total N.

	S SUM	SC SUM	SDD SUM	SWD SUM	N SUM	NC SUM	NDD SUM	NWD SUM	TOTAL SUM
1971	12.4	20.3	12.7	4.3	14.3	19.4	17.7	5.7	13.5
1972	11.0	11.7	9.7	11.5	14.8	16.7	12.6	15.0	13.2
1973	7.6	11.0	7.8	4.0	10.7	17.2	9.4	5.6	9.5
1974	20.4	15.8	21.7	23.6	18.3	15.8	19.7	19.6	19.1
1975	16.7	16.8	17.1	16.3	17.9	19.9	17.5	16.4	17.4
1976	20.6	23.5	25.6	12.7	21.2	24.2	24.6	14.7	20.9
1977	20.9	23.4	22.8	16.4	14.3	12.8	15.4	14.6	16.9
1978	17.0	16.6	15.8	18.6	14.8	12.7	13.6	18.0	15.7
1979	12.3	9.4	6.3	21.3	14.7	11.8	11.9	20.6	13.8
1980	26.0	24.7	27.9	25.4	25.2	23.3	26.4	25.8	25.5
1981	22.4	22.3	23.5	21.4	22.0	22.0	22.2	22.0	22.2
1982	16.9	14.3	14.2	22.1	12.5	9.6	10.6	17.3	14.3
1983	7.7	7.2	5.4	10.5	10.9	10.9	9.1	12.8	9.6
1984	22.9	25.4	27.0	16.2	19.2	20.8	20.3	16.5	20.7
1985	8.7	7.6	10.2	8.2	9.6	7.6	10.7	10.5	9.2
1986	21.0	19.1	19.3	24.7	18.9	19.4	17.6	19.6	19.7
1987	17.1	11.7	15.8	23.8	19.3	14.8	19.3	24.0	18.4
1988	18.1	20.8	22.2	11.4	19.2	22.9	22.7	11.9	18.8
1989	8.8	8.5	9.1	8.8	12.5	12.8	13.4	11.3	11.0
1990	10.4	8.3	7.6	15.2	14.5	12.5	11.2	19.7	12.8
1991	13.2	9.1	11.4	18.9	13.3	10.2	11.5	18.0	13.2
1992	25.4	26.8	24.8	24.5	18.7	17.4	17.8	20.9	21.4
1993	14.4	15.5	13.9	13.9	11.0	11.3	10.6	11.0	12.4
1994	17.7	20.1	16.9	16.1	17.3	18.5	15.0	18.4	17.5
1995	12.4	15.4	15.5	6.4	15.4	17.1	20.0	9.1	14.2
1996	12.8	12.8	10.7	14.8	13.0	11.5	10.7	16.8	12.9
1997	18.0	18.8	17.8	17.3	16.8	14.3	13.8	22.2	17.2
1998	3.1	3.4	2.7	3.2	8.7	11.0	9.2	5.8	6.4
1999	13.8	9.7	9.3	22.4	11.1	10.9	12.7	9.7	12.2
2000	15.5	15.1	20.3	11.0	15.0	15.7	17.9	11.6	15.2

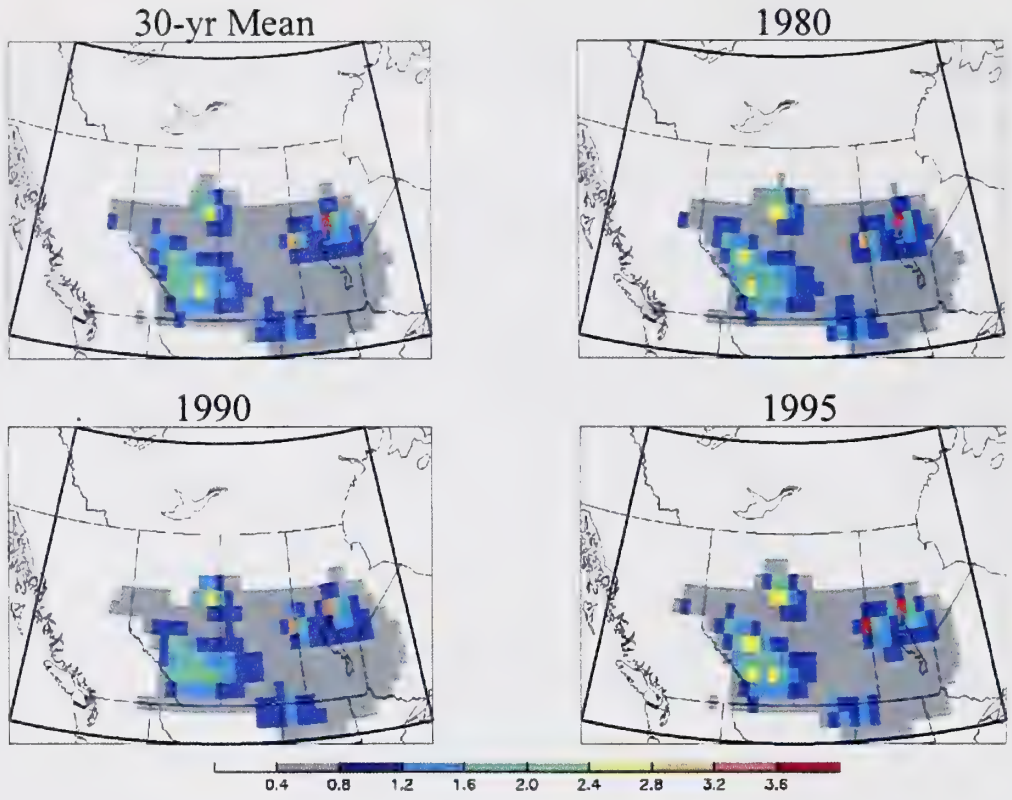

Figure III.1 Total sulphur concentration (□g m-3) for the years 1980, 1990, and 1995 along with 30-year mean.

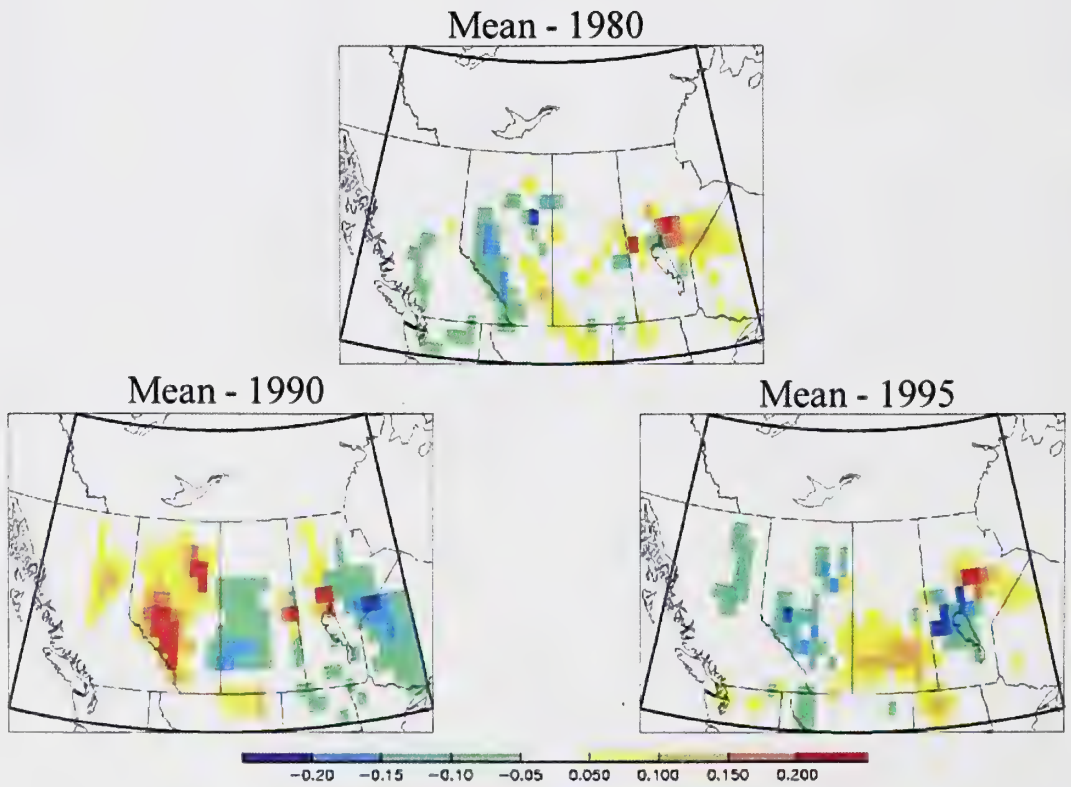

Figure III.2 Difference in total sulphur concentration (□g m-3) between 30-year mean and each of the years 1980, 1990, and 1995.

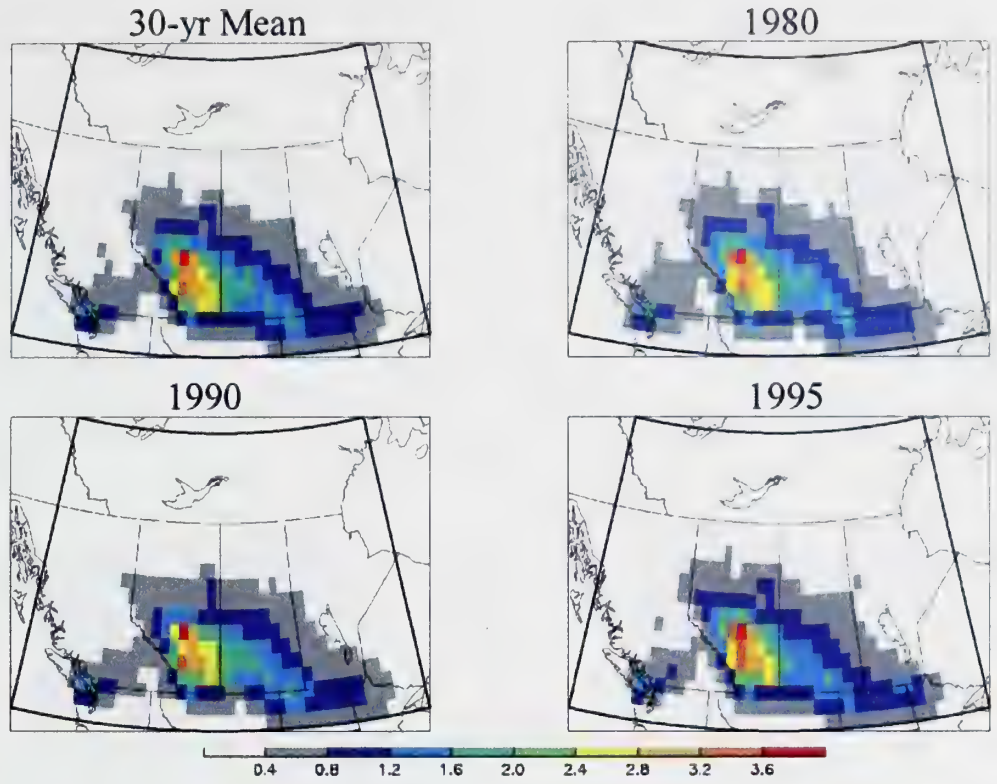

Figure III.3 **Total nitrogen concentration (□g m-3) for years 1980, 1990, and 1995 along with 30-year mean.**

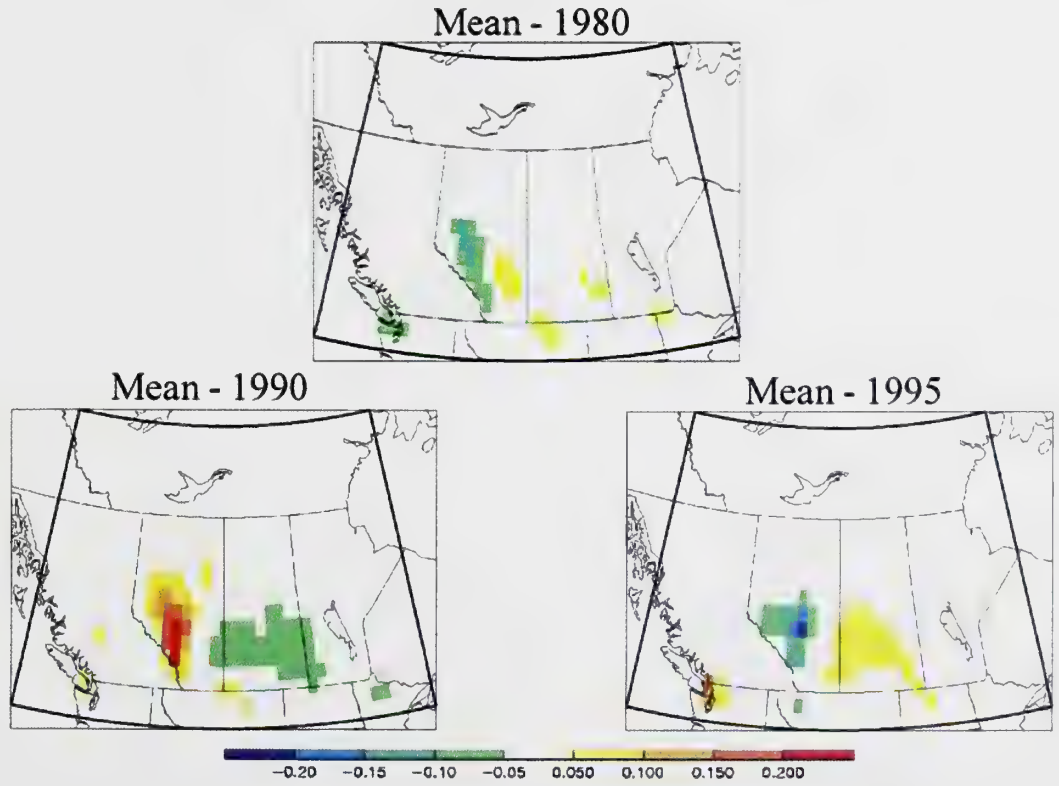

Figure III.4 Difference in total nitrogen concentration (μg m^{-3}) between 30-year mean and each of the years 1980, 1990, and 1995.

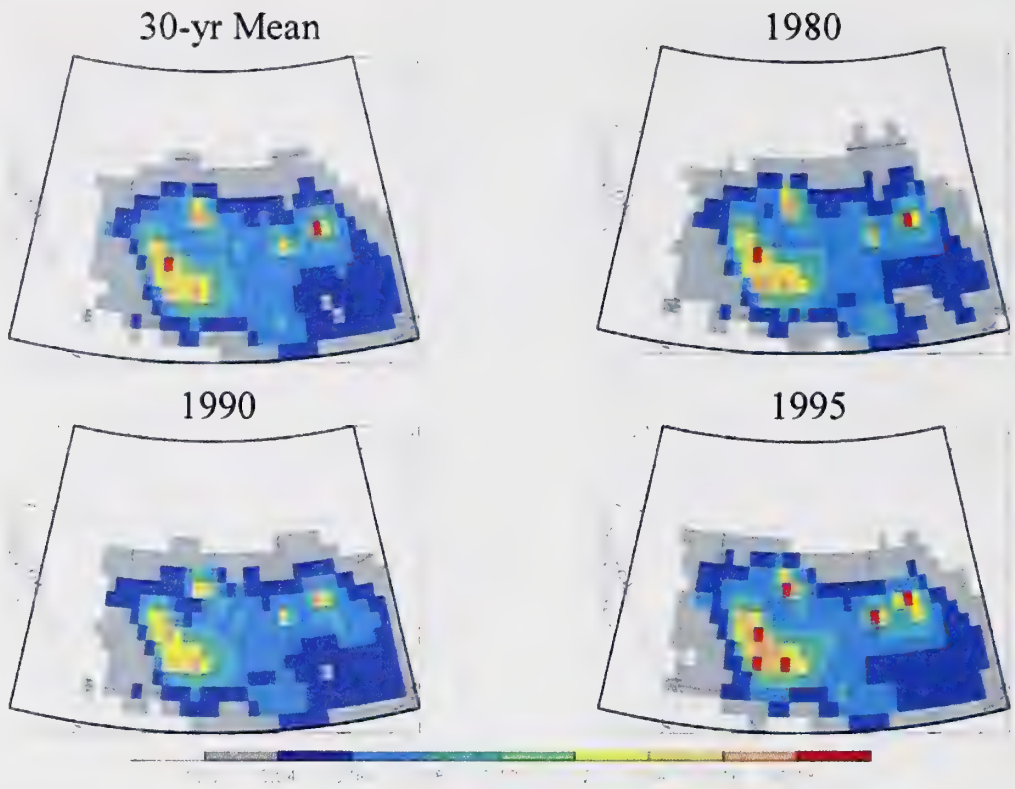

Figure III.5 Total sulphur deposition (keq/ha/y) for years 1980, 1990, and 1995 along with 30-year mean.

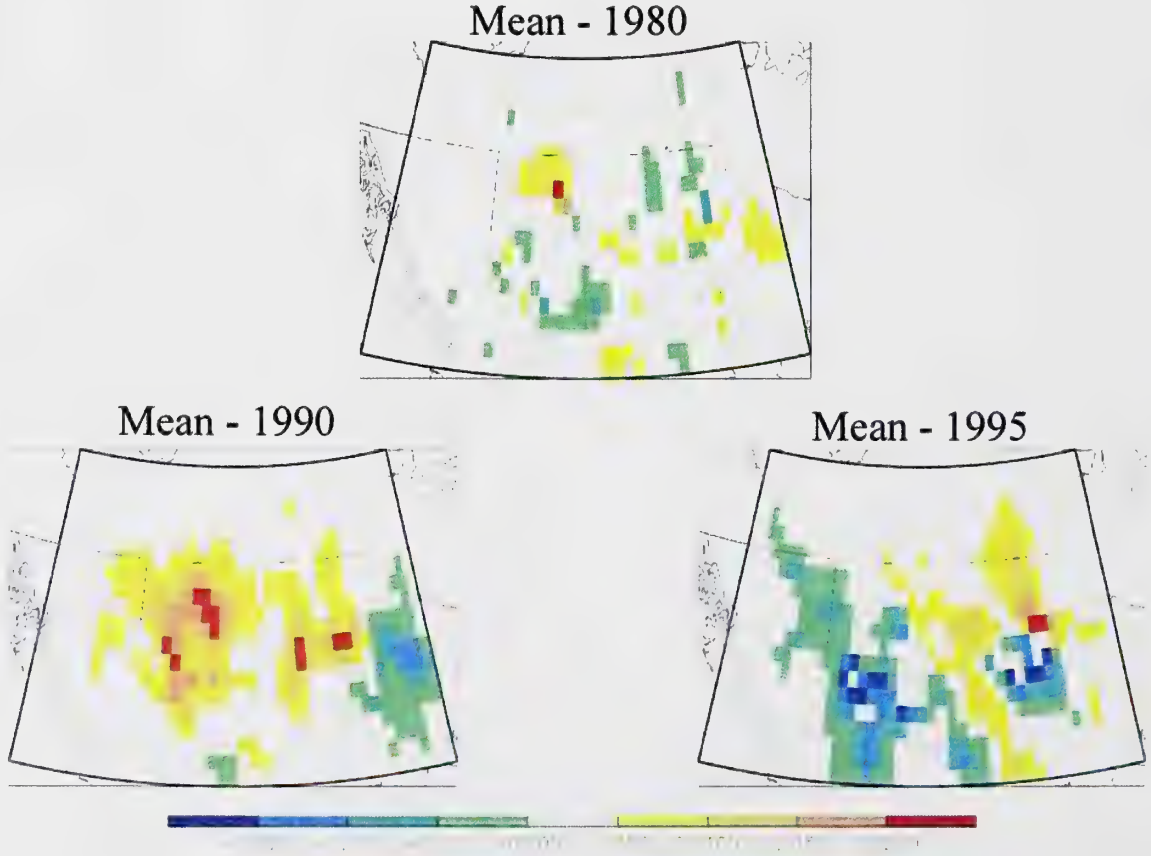

Figure III.6 Difference in total sulphur deposition (keq/ha/y) between 30-year mean and each of the years 1980, 1990, and 1995.

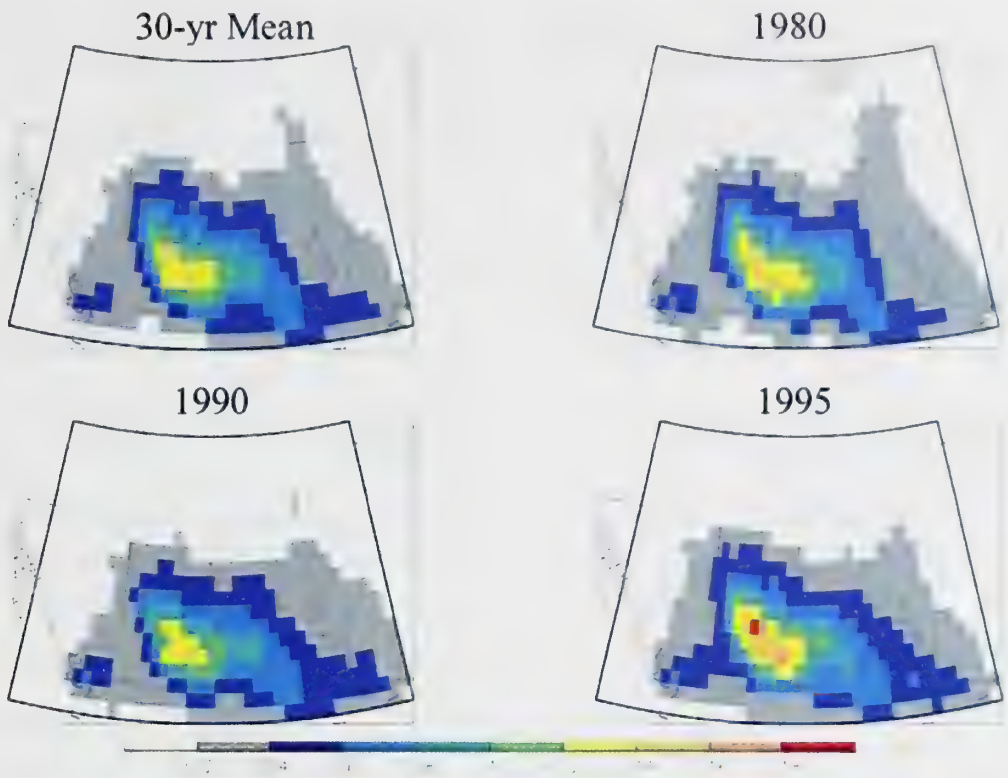

Figure III.7 Total nitrogen deposition (keq/ha/yr) for years 1980, 1990, and 1995 along with 30-year mean.

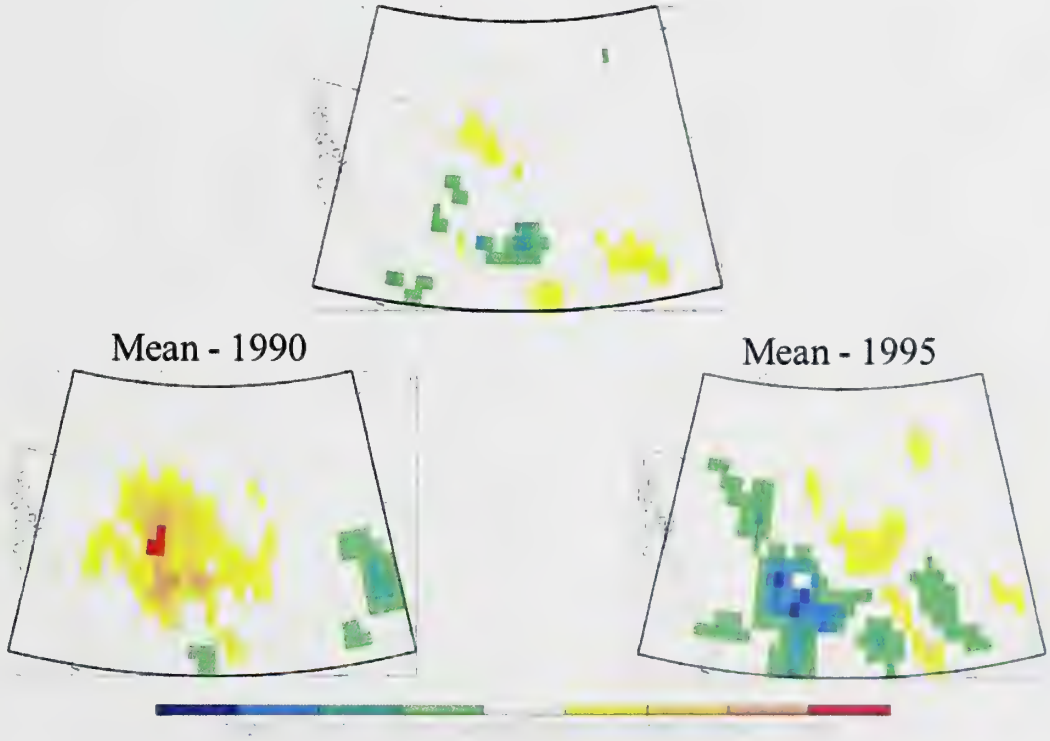

Figure III.8 Difference in total nitrogen deposition (keq/ha/yr) between 30-year mean and each of the years 1980, 1990, and 1995.

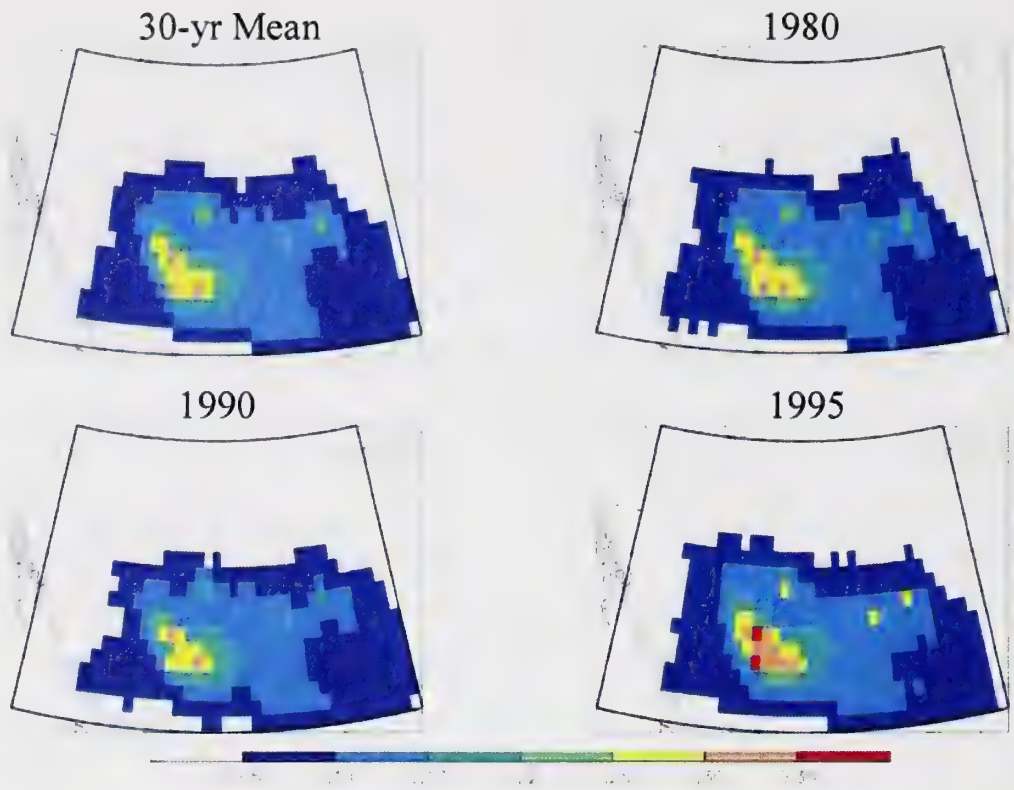

Figure III.9 Total nitrogen and sulphur deposition (keq/ha/yr) for years 1980, 1990, and 1995 along with 30-year mean.

APPENDIX IV SUPPORTING DOCUMENTATION FOR FIELD STUDIES OF SOIL AND SURFACE WATER QUALITY IN RELATION TO ACID DEPOSITION IN ALBERTA

Table IV.1 Sensitivity categories of mineral soils in Alberta (after Holowaychuk and Fessenden, 1987).

Cation Exchange Capacity (cmol(+)/kg)	pH	Relative Base Loss	Acidification	Aluminum Solubilization	Overall Sensitivity Rating
<6	< 4.6	H*	L	H	H
<6	4.6 - 5.0	H	L	H	H
<6	5.1 - 5.5	H	M	H	H
<6	5.6 - 6.0	H	H	M	H
<6	6.1 - 6.5	H	H	L	H
<6	> 6.5	L	L	L	L
6 - 15	< 4.6	H	L	H	H
6 - 15	4.6 - 5.0	M	L	H	M
6 - 15	5.1 - 5.5	M	L-M	M	M
6 - 15	5.6 - 6.0	M	L-M	L-M	M
6 - 15	> 6.0	L	L	L	L
> 15	< 4.6	H	L	H	H
> 15	4.6 - 5.0	M	L	H	M
> 15	5.1 - 5.5	M	L	M	M
> 15	5.6 - 6.0	L	L-M	L-M	L
> 15	> 6.0	L	L	L	L

*L, M, H: low, medium, high sensitivity

Table IV.2 Peatland classification in Alberta by chemical properties of soils and associated waters (after Holowaychuk and Fessenden, 1987).

Peatland System	Soil pH	Exchangeable Bases (cmol(+)/L)	% Base Saturation	pH	Ca^{2+} and Mg^{2+} (cmol(+)/L)
eutrophic	6.0 - 8.0	8 - 10	70 - 100	6.5 - 8.0	2 - 5
mesotrophic	4.5 - 6.0	2 - 8	25 - 70	5.0 - 6.5	0.5 - 2
oligotrophic					
- organic soils	3.5 - 5.5	0 - 2	10 - 25	3.5 - 5.5	>0.5
- organic cryosol	3.5 - 5.5	0 - 6	5 - 50	3.5 - 5.0	<0.5

Table IV.3 Sensitivity classification of organic soils (after Holowaychuk and Fessenden, 1987).

	Sensitivity to			Overall Sensitivity
Peatland System	Base Loss	Acidification	Al Solubilization	Rating
eutrophic	L	L	L	L
mesotrophic	H	H	M	H
oligotrophic				
- organic soils	L	L	H	L
- organic cryosol	L	L	H	L

Table IV.4 Sensitivity classification of organic soils (after Erickson, 1987).

Total Alkalinity (mg $CaCO_3$ equivalents/L)	Sensitivity Rating
0 - 10	high
11 - 20	moderate
21 - 40	low
> 40	least

Table IV.5 Receptor sensitivity assignments for grid cells used in RELAD modeling of Alberta (after AENV, 1999).

Criteria	Sensitivity Rating of Grid Cell	Critical Load (keq H^+/ha/yr)	Target Load (keq H^+/ha/yr)	Monitoring Load (keq H^+/ha/yr)
≥5% of area contained within a grid cell rated as sensitive	sensitive	0.25	0.22	0.17
<5% of area sensitive, but total of sensitive and moderately sensitive areas ≥5% of grid cell area	moderate sensitivity	0.50	0.45	0.35
all other cells	low sensitivity	1.00	0.90	0.70

Table IV.6 Preliminary texture sensitivity ratings of soils located in the Provost-Esther area of Alberta (after AENV, 2001).

Soil Texture	Sensitivity Rating
sand	sensitive
loamy sand	
sandy loam	moderately sensitivity
fine sandy loam	low sensitivity
very fine sandy loam	

Table IV.7 Limits used by Alberta Research Council model for determining critical load values for soils in Alberta (after AENV, 2001).

Critical Acid Deposition Concentration (keq H^+/ha/yr)	Time to Reach Level (years)	Sensitivity Rating
≥0.2	100	sensitive
0.2 - 0.5	50	sensitive
0.2 - 0.5	100	moderate sensitivity
0.5 - 1.0	50	moderate sensitivity
0.5 - 1.0	100	low sensitivity
>1.0	50	low sensitivity

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